DESIGN OF CMAS PROCESS TO TREAT 1 MLD OF MUNICIPAL WASTEWATER

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Q. Problem statement:

→ primary effluent flow = 1000 m^3/d

→ Aeration basin mixed-liquor temperature = 12 °c

→ Waste water characteristics

a). BOD → 200 mg/L

b). sBOD → 65 mg/L

c). COD → 400 mg/L

d) sCOD → 125 mg/L

e). rbCOD → 85 mg/L

f) TSS → 72 mg/L

g) VSS → 65 mg/L

h) TKN → 30 mg/L

g i) NH_4-N → 30 mg/L

j) TP → 6 mg/L

k) Alkalinity → 150 mg/L as $CaCO_3$.

l) bCOD/BOD ratio → 1.6

→ Design conditions and assumptions:

1. Fine bubble ceramic diffusers with an aeration clean water O_2 transfer efficiency = 35%.
2. Liquid depth for the aeration basin = 4.9m.
3. The point of air release for the ceramic diffuser is 0.5 m above the tank bottom.
4. DO in aeration basin = 2.0 g/m^3.
5. Site elevation is 500m (pressure = 95.6 kPa)
6. Aeration factor α = 0.5 for BOD removal only and 0.65 for nitrification β = 0.95 for both conditions, and diffuser fouling factor F = 0.90

7. Use kinetic coefficients given in Tables 8-10 & 8-11.

8. SRT for BOD removal = 5 days.

9. Design MLSS X_{TR} concentration = 3000 g/m^3; values of 2000 to 3000 g/m^3 can be considered.

10. TKN peak/average factor of safety FS = 1.5.

SOLUTION

PART A : BOD REMOVAL WITHOUT NITRIFICATION.

Step 1: Develop the wastewater characteristics needed for design.

a). Find bCOD using Eq. 8-8. $1 g/m^3 = 1 mg/L$

$$bCOD = \sim 1.6 (BOD)$$
$$= 1.6 \times 200 \ g/m^3 = 320 \ g/m^3.$$

b). find nbCOD using Eq. 8-7.

$$COD = bCOD + nbCOD$$
$$nbCOD = COD - bCOD = 400 - 320 = 80 \ mg/L$$

c). Find effluent $sCOD_e$ (assumed to be non-biodegradable).

$$sCOD_e = sCOD - 1.6 \ sBOD$$
$$= 125 - 1.6 \times 65 = 21 \ g/m^3.$$

d). Find nbVSS using Eq. 8-4.

$$nbVSS = (1 - bp \ COD/pCOD) \ VSS.$$

$$\frac{bpCOD}{pCOD} = \frac{(bCOD/BOD)(BOD - sBOD)}{COD - sCOD}$$

$$= \frac{1.6 (BOD - sBOD)}{COD - sCOD} = \frac{1.6 [200 - 65]}{[400 - 125]}$$

$$= 0.785$$

$$nbVSS = (1 - 0.785) \times 65 \ g/m^3$$

$$= \underline{13.95 \ g/m^3}$$

c). Find iTSS

$iTSS = TSS - VSS$

$= 72 - 65 = \underline{7\ g/m^3}$

Step 2: Design suspended growth system for BOD removal only.

a). Determine biomass production using parts A and B of Eq. 8-15.

$$P_{x,VSS} = \frac{QY(S_o - S)}{1 + k_d(SRT)} + \frac{(f_d)(k_d)QY(S_o - S)SRT}{1 + (k_d)SRT}$$

Define input data for above equations:

$Q = 1000\ m^3/d$

$Y = 0.4\ g\ VSS/g\ bCOD$ (from Table 8-10)

$S_o = 320\ g\ bCOD/m^3$ (from step 1)

Determine S from Eq. 7-40 in Table 8-5, Note $Yk = \mu_m$.

$$S = \frac{K_s(1 + k_d\ SRT)}{SRT(\mu_m - k_d) - 1}$$

Use μ_m and k_d from Table 8-10.

$K_s = 20\ g/m^3$ (Table 8-10)

$\mu_{m,T} = \mu_m \theta^{T-20}$

$\mu_{m,12} = 6.0\ g/g \cdot d \times 1.07^{12-20} = 3.5\ g/g \cdot d$

$k_{d,T} = k_d \theta^{T-20}$

$k_{d,12} = 0.12 \times 1.04^{12-20} = 0.088\ g/g \cdot d$

$$S = \frac{(20\ g/m^3)(1 + 0.088 \times 5)}{5((3.5 - 0.088) - 1)} = 1.8\ g\ bCOD/m^3$$

b). Substitute the above values in the expressions given above and solve for $P_{x,VSS}$.

$$P_{x,VSS} = \frac{1000 \times 0.4(320 - 1.8)}{1 + 0.088 \times 5} + \frac{0.15 \times 0.088 \times 1000 \times 0.4 \times (320 - 1.8) \times 5}{1 + 0.088 \times 5}$$

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$= (88\,388.889 + 5833.66) \times 10$

$P_{x,VSS} = 94.22$ kg VSS/d

Step 3: Determine the mass of VSS and TSS in the aeration basin. The mass of VSS and TSS can be determined using Eq. (7-54) and Eq. 7-55 given in Table 8-5.

$$Mass = P_X (SRT)$$

a). Determine $P_{x,VSS}$ and $P_{x,TSS}$ using Eqs. 8-15 and 8-16 including parts A, B, and D. Part C = 0 because there is no nitrification.

From Eq. 8-15, $P_{x,VSS}$ is:

$$P_{x,VSS} = 94.22 \text{ kg/d} + Q(\text{nb VSS})$$

$$= 94.22 \text{ kg/d} + (1000 \text{ m}^3/\text{d}) \times (13.95 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})$$

$$= 108.17 \text{ kg/d}$$

From Eq. 8-16, $P_{x,TSS}$ is

$$P_{x,TSS} = \left[\frac{A}{0.85} + \frac{B}{0.85} + \frac{C}{0.85} + D + Q(TSS_o - VSS_o)\right]$$

$$P_{x,TSS} = \frac{94.22}{0.85} + 13.95 + 1000 \text{ m}^3/\text{d}\,(7 \text{ g/m}^3) \times 10^{-3} (\text{kg/g})$$

$$= 131.79 \text{ kg/d}$$

b). Calculate the mass of VSS and TSS in the aeration basin

(i). Mass of MLVSS using Eq. 7-54 in Table 8-5

$$(X_{VSS})(V) = (P_{x,VSS})\,SRT$$

$$= \cancel{MAX} = (108.17 \text{ kg/d})(5\text{d})$$

$$= 540.85 \text{ kg}$$

(ii). Mass of MLSS using Eq. (7-55) in Table 8-5

$$(X_{TSS})(V) = (P_{x,TSS})\,SRT = 131.79 \times 5 = 658.95 \text{ kg}$$

Step 4: Select a design MLSS mass concentration and determine the aeration tank volume and detention time using the TSS mass computed in step 3.

a). Determine the aeration ~~work~~ tank volume using the relationship from step 3b.

$$(V)(X_{TSS}) = 658.95 \text{ kg}.$$

At $X_{TSS} = 3000 \text{ g/m}^3$;

$$V = \frac{658.95 \times 10^3 \text{ g}}{3000 \text{ g/m}^3} = 219.65 \text{ m}^3$$

b). Determine the aeration tank detention time:

Use 2 basins of $V = 110 \text{ m}^3$ so that one can be taken off while maintenance

$$\tau = \frac{V}{Q} = \frac{(219.65 \text{ m}^3)(24 \text{ h/d})}{(1000 \text{ m}^3/\text{d})} = 5.27 \text{ h}$$

c). Determine MLVSS.

$$\text{Fraction VSS} = \frac{540.85 \text{ kg VSS}}{658.95 \text{ kg TSS}} = 0.82$$

$$\text{MLVSS} = 0.82 \times 3000 \text{ mg/L} = 2460 \text{ g/m}^3$$

Step 5: Determine F/M and BOD volumetric loading.

a). Determine F/M using Eq. (7-60) in Table 8-5.

$$F/M = \frac{QS_0}{XV} = \frac{\text{kg BOD}}{\text{kg MLVSS-d}}$$

$$= \frac{(1000 \text{ m}^3/\text{d})(200 \text{ g/m}^3)}{(2460 \text{ g/m}^3)(219.65 \text{ m}^3)}$$

$$= 0.37 \text{ kg/kg·d}$$

b). Determine volumetric BOD loading

$$\text{BOD loading} = \frac{QS_0}{V} = \frac{\text{kg BOD}}{\text{m}^3\text{.d}} = \frac{1000 \times 200}{219.65 \times 10^3} = 0.91 \frac{\text{kg}}{\text{m}^3\text{d}}$$

Step 6: Determine the observed yield based on TSS and VSS

a). Observed yield = g TSS/g bCOD = kg TSS/kg bCOD

$P_{x,TSS}$ = 131.79 kg/d

bCOD removed = $Q(S_0 - S)$

= 1000 m³/d (320 − 1.8) g/m³ × 10^{-3}

= 318.2 kg/d

$$Y_{obs,TSS} = \frac{131.79}{318.2} = 0.414 \frac{\text{kg TSS}}{\text{kg bCOD}} = 0.414 \frac{\text{g TSS}}{\text{g bCOD}}$$

$$= 0.414 \frac{\text{g TSS}}{\text{g bCOD}} \times \frac{1.6 \text{ g bCOD}}{\text{g BOD}} = 0.66 \text{ g TSS/g BOD}$$

b). observed yield based on VSS

$Y_{obs,VSS}$: VSS/TSS = 0.82 (from step 4c)

$$= \left(0.414 \frac{\text{g TSS}}{\text{g bCOD}}\right)\left(\frac{0.82 \text{ g VSS}}{\text{g TSS}}\right)$$

= 0.34 g VSS/g bCOD

= 0.54 g VSS/bBOD

Step 7: Calculate the O_2 demand using Eq. (7-59) in Table 8-5.

$$R_0 = Q(S_0 - S) - 1.42 P_{x,bio}$$

$$= 1000 \times 10^{-3} (320 - 1.8) - 1.42 \times 94.22$$

= 184.4 kg/d = 7.68 kg/h

Step 8: Fine bubble aeration design − determine air flowrate at average design flowrate using Eq. (5-55)

$$AOTR = SOTR \left(\frac{\beta C_{\bar{s},T,H} - C_L}{C_{s,20}}\right)(1.024^{T-20})(\alpha)(F)$$

where AOTR = actual oxygen transfer rate under field conditions, kg O_2/h

SOTR = Standard oxygen transfer rate in tap water at 20°C and zero dissolved oxygen, kg O_2/h.

a). Determine $C_{\bar{s},T,H}$ - the average dissolved oxygen saturation concentration in clean water in aeration tank at temperature T and altitude H, using the following relationship from Eq. (5-55).

$$C_{\bar{s},T,H} = (C_{s,T,H})\frac{1}{2}\left(\frac{P_d}{P_{atm}} + \frac{O_t}{21}\right)$$

(i). From Table D-1 (Appendix D), $C_{20} = 9.08$ mg/L and $C_{12} = 10.77$ mg/L.

(ii). Determine the relative pressure at elevation 500m to correct the DO concentration for altitude.

From Appendix B,

$$\frac{P_b}{P_a} = \exp\left[-\frac{gM(z_b - z_a)}{RT}\right]$$

$$= \exp.\left\{-\frac{(9.81\ m/s^2)(28.97\ kg/kg\text{-mole})[(500-0)m]}{(8314\ kg.m^2/s^2.kg\text{-mole}.K)[(273.15+12)K]}\right\}$$

$$= 0.94$$

The oxygen concentration at 500m and 12°C is

$$C_{s,T,H} = 10.77\ mg/L \times 0.94 = 10.12\ mg/L$$

(iii). Determine atmospheric pressure in m of water at an elevation of 500m and a temperature of 12°C (see Appendix B and C).

$$P_{atm,H} = \frac{(P_{atm,H}\ kN/m^3)}{(\gamma\ kN/m^3)} = \frac{(0.94)(101.325\ kN/m^2)}{(9.802\ kN/m^3)}$$

$$= 9.72\ m$$

(iv). Determine the oxygen concentration assuming the percent oxygen concentration leaving the aeration tank is 19%.

$$C_{\bar{s},T,H} = (C_{s,T,H})(1/2)\left(\frac{P_{atm,H} + P_{w,\,Eff\ depth}}{P_{atm,H}} + \frac{O_t}{21}\right)$$

$$= (10.12\ mg/L)(1/2)\left[\frac{9.72m + (4.9 - 0.5)m}{9.72m} + \frac{19}{21}\right]$$

$$= 11.93\ mg/L$$

b). Determine the SOTR using $\alpha = 0.5$, $\beta = 0.95$, and diffuser fouling factor $F = 0.9$.

$$SOTR = AOTR\left[\frac{C_{s,20}}{\alpha F(\beta C_{\bar{s},TH} - C)}\right](1.024^{20-T})$$

$$= \frac{(7.68\ kg/h)(9.08\ g/m^3)(1.024^{20-12})}{(0.5)(0.9)[(0.95)(11.93\ g/m^3) - 2.0\ g/m^3]}$$

$$= 20\ kg/h$$

c). Determine the air flowrate

$$\text{Air flowrate, kg/min} = \frac{(SOTR\ kg/h)}{[(E)(60 min/h)(kg\,O_2/m^3\,air)]}$$

Using the data given in Appendix B, the density of air at 12°C and a pressure of 95.2 kPa (0.94×101.325 kPa) is 1.1633 kg/m³. The corresponding amount of oxygen by weight is 0.270 (0.2318×1.1633 kg/m³). Thus, the required air flowrate is :

$$\text{Air flowrate, } m^3/min = \frac{(20\ kg/h)}{[(0.35)(60\ min/h)(0.270\ kg\,O_2/m^3\,air)]}$$

~~= 55.5 m³/min.~~

$$= 3.53\ m^3/min$$

Part B, BOD Removal and Nitrification.

Step 9: Perform the nitrification design following the same steps as for BOD removal except the design SRT must first be determined. Determine the specific growth rate μ_n for the nitrifying organisms using Eq. (7-93). The nitrification rate will control the design because the nitrifying organisms grow more slowly than the heterotrophic organisms that remove organic carbon.

$$\mu_n = \left(\frac{\mu_{n,m} N}{K_n + N}\right)\left(\frac{DO}{K_o + DO}\right) - k_{dn}.$$

a). Find $\mu_{n,m}$ at $T = 12°C$.

$$\mu_{n,m,12°C} = (0.75\ g/g \cdot d)(1.07)^{12-20} = 0.44\ g/g \cdot d$$

b). Find K_n, at $T = 12°C$.

$$K_{n,12°C} = (0.74\ g/m^3)(1.053)^{12-20} = 0.49\ g/m^3.$$

c). Find k_{dn}, at $T = 12°C$.

$$k_{dn,12°C} = (0.08\ g/g \cdot d)(1.04)^{12-20} = 0.06\ g/g \cdot d.$$

d). Substitute the above and given values in Eq. (7-93) and solve for μ_n.

$N = 0.50\ g/m^3$, $DO = 2.0\ g/m^3$, $K_o = 0.50\ g/m^3$

$$\mu_n = \left\{\frac{(0.44\ g/g d)(0.50\ g/m^3)}{[0.49 + 0.5]\ g/m^3}\right\}\left\{\frac{(2.0\ g/m^3)}{[(0.5 + 2.0)\ g/m^3]}\right\} - 0.06\ g/g \cdot d$$

$$= 0.12\ g/g d$$

Step 10: Determine the theoretical and design SRT.

a). Find theoretical SRT using Eq. (7-37) in Table 8-5.

$$SRT = \frac{1}{\mu_n} = \frac{1}{(0.12\ g/g d)} = 8.33\ d$$

b). Determine the design SRT using Eq. (7-71).

FS = TKN peak / TKN average = ~~1.5~~ 1.5

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Design SRT = (FS)(theoretical SRT)
= 1.5 (8.33 d) = 12.5 d

Step 11: Determine biomass production using Eq. (8-15), parts A, B, and C.

$$P_{x,bio} = \frac{QY(S_0 - S)}{1 + (k_d)SRT} + \frac{(f_d)(k_d)QY(S_0 - S)SRT}{1 + (k_d)SRT} + \frac{QY_n(NO_x)}{1 + (k_{dn})SRT}$$

a). Define input data for the above equations.

$Q = 1000\ m^3/d$

$Y = 0.40\ VSS/g \cdot bCOD$

$S_0 = 320\ g\ bCOD/m^3$ (from step 1)

$k_d = 0.088\ g/g \cdot d$ (from step 2)

$\mu_m = 3.5\ g/g \cdot d$ (from step 2)

Determine S from Eq. (7-40) in Table 8-5.

$$S = \frac{K_s[1 + (k_d)SRT]}{SRT(\mu_m - k_d) - 1}$$

$$S = \frac{(20\ g/m^3)(1 + (0.088\ g/g \cdot d)(12.5\ d))}{(12.5\ d)[(3.5 - 0.088)\ g/g \cdot d] - 1} = 1.0\ g\ bCOD/m^3$$

$Y_n = 0.12\ g\ VSS/g\ NO_x$ (from table 8-11)

$k_{dn,12°C} = 0.06\ g/g \cdot d$ (from step 9e)

Assume $NO_x \approx 80\%$ (TKN) as nitrogen balance cannot be done yet. The error in assuming that the $NO_x \approx 80\%$ (TKN) is small as the nitrifier VSS yield is a small fraction of total MLVSS concentration.

$NO_x = 0.8(30) = 24\ g/m^3$

b). Substitute the above values in the expression given above and solve for $P_{x,bio}$

$$P_{x,bio} = \frac{(1000) \times 0.4 \times (320 - 1) \times 10^{-3}}{(1 + 0.088 \times 12.5)} + \frac{0.15 \times 0.088 \times 0.4 \times 1000 \times (320 - 1) \times 12.5 \times 10^{-3}}{(1 + 0.088 \times 12.5)}$$

$$+ \frac{1000 \times 0.12 \times 24 \times 10^{-3}}{(1 + 0.06 \times 12.5)}$$

$$= 60.76 \text{ kg/d} + 10.03 \text{ kg/d} + 1.65 \text{ kg/d}$$

$$= 72.43 \text{ kg VSS/d}$$

Step 12: Determine the amount of nitrogen oxidized to nitrate. The amount of nitrogen oxidized to nitrate can be found by performing a nitrogen balance using Eq. (8-18)

$$NO_x = TKN - N_e - 0.12\, P_{x,bio}/Q$$

$$= (30 - 0.5)\text{g/m}^3 - \frac{(0.12 \text{ gN/gVSS})(72.43 \text{ kg VSS/d})(10^3 \text{ g/kg})}{(1000 \text{ m}^3/\text{d})}$$

$$= (30 - 0.5 - 8.6916)\text{ g/m}^3$$

$$= 20.81 \text{ g/m}^3$$

Step 13: Determine the concentration and mass of VSS and TSS in the aeration basin.

Mass = P_x (SRT)

a). Calculate the concentration of VSS and TSS in the aeration basin.

(i). $P_{x,VSS}$, use Eq. (8-15). Part A, B, and C have already been calculated above as $P_{x,bio}$. Part D must be added to determine $P_{x,VSS}$.

$$P_{x,VSS} = (72.43 \text{ kg VSS/d}) + Q(\text{nb VSS})$$

$$= 72.43 + (1000 \text{ m}^3/\text{d})(20 \text{ g/m}^3)(10^{-3} \text{ kg/g})$$

$= 92.43$ kg/d

(ii). $P_{x,TSS}$, use Eq.(8-16), with the term E added to account for inert influent TSS.

$$P_{x,TSS} = \frac{72.43}{0.85} + 20 + 1000 \times (10 g/m^3) \times 10^{-3}$$

$$= 85.21 + 20 + 10$$

$$= 115.21 \text{ kg/d}$$

b) Calculate the mass of VSS and TSS in the aeration basin eqs.(7-54) and (7-55) in Table 8-5.

(i). Mass of MLVSS

$$(X_{VSS})V = (P_{x,VSS})SRT$$

$$= 92.43 \times 12.5 d$$

$$= 1155.375 \text{ kg}$$

(ii). Mass of MLSS

$$(X_{TSS})V = (P_{x,TSS})SRT$$

$$= (115.21 \text{ kg/d}) \times 12.5 d$$

$$= 1440.125 \text{ kg}$$

Step 14: Select a design MLSS mass concentration and determine the aeration tank volume and detention time using the TSS mass computed in step 6.

a). Determine the aeration tank volume using the relationship from step 6b.

$$V X_{TSS} = 1440.125 \text{ kg}$$

At MLSS $= 3000$ mg/L

$$V = \frac{(1440.125 \text{ kg})(10^3 \text{ g/kg})}{(3000 \text{ g/m}^3)} = 480 \text{ m}^3$$

b). Determine the aeration tank

~~Use~~ ~~Set~~ Vic ~~Ol~~ basins of volume $240\ m^3$

$$\tau = \frac{V}{Q} = \frac{480\ m^3 \times 24\ h/d}{1000\ m^3/d} = 11.52\ h$$

c). Determine MLVSS.

$$\text{Fraction VSS} = \frac{1155.375}{1440.125} = 0.8$$

$$MLVSS = 0.8 \times 3000\ g/m^3 = 2400\ g/m^3$$

Step 15: Determine F/M and BOD volumetric loading.

a). Determine F/M using Eq. (7-60)

$$F/M = \frac{QS_o}{XV} = \frac{g\ BOD}{g\ MLVSS \cdot d}$$

$$= \frac{(1000\ m^3/d)(200\ g/m^3)}{(\overset{2400}{\cancel{10^3}}\ g/kg)(480\ m^3)} = \overset{0.17}{\cancel{0.42}}\ kg/m^3 d.$$

b). Determine L_{org} → $L_{org} = 0.42\ kg/m^3.d$

Note: Both the F/M and L_{org} loading are in the low-to-mid-range of the design parameters given later in this chapter in Table 8-16.

b).

Step 16: Determine the observed yield based on TSS and VSS.

observed yield = $g\ TSS/g\ bCOD$ = $kg\ TSS/kg\ bCOD$.

$P_{x,TSS} = 115.21\ kg/d$.

$$bCOD\ removed = Q(S_o - S)$$

$$= (1000\ m^3/d)(320 - 1)\ g/m^3\ (1\ kg/10^3 g)$$

$$= 319\ kg/d$$

a). Observed yield based on TSS.

$$Y_{obs,TSS} = \frac{115.21\ kg/d}{319\ kg/d} = 0.36\ \frac{kg\ TSS}{kg\ bCOD} = 0.36\ \frac{g\ TSS}{g \cdot bCOD}$$

$= \left(\frac{0.36\ g\ TSS}{g\ bCOD}\right)\left(\frac{1.6\ g\ bCOD}{g\ BOD}\right)$

$= 0.65\ g\ TSS/g\ BOD$

b). observed yield based on VSS

$Y_{obs,VSS}$: VSS/TSS = 0.80 (from step 4c)

$= \left(\frac{0.36\ g\ TSS}{g\ bCOD}\right)\left(\frac{0.80\ g\ VSS}{g\ TSS}\right)$

$= 0.29\ g\ VSS/g\ bCOD$

$= \left(\frac{0.29\ g\ VSS}{g\ bCOD}\right)\left(\frac{1.6\ g\ bCOD}{g\ BOD}\right)$

$= 0.46\ g\ VSS/g\ BOD$

Step 17: Calculate the O_2 demand using Eq. (8-17)

$R_o = Q(S_o - S) - 1.42\ P_{x,bio} + 4.33\ Q\ (NO_x)$

$= 1000 \times (320 - 1) \times 10^{-3} - 1.42 \times 72.43 + 4.33 \times 1000 \times 20.81 \times 10^{-3}$

$= 319 - 102.85 + 90.1$

$= 306.25\ kg/d = 12.76\ kg/h$

Step 18: Fine bubble aeration design - determine air flowrate at average design flowrate (step 8).

a). Determine the SOTR using the values given the problem statement: $\alpha = 0.65$, $\beta = 0.95$, & $F = 0.9$.

$$SOTR = AOTR\left[\frac{C_{s,20}}{\alpha F(\beta C_{s,T,H} - C)}\right](1.024^{20-T})$$

$$= \frac{(12.76\ kg/h)(9.08\ g/m^3)(1.024)^{20-12}}{(0.65)(0.9)\ [0.95 \times 11.93 - 2]}$$

$= 25.65\ kg/h$

b) Determine the air flowrate

$$\text{Air flowrate, } m^3/min = \frac{(25.65 \ kg/h)}{[0.35 \times 60 \times 0.270]}$$

$$= \cancel{90.5} \ 4.524 \ m^3/min.$$

Step 19: Check alkalinity.

a). Prepare an alkalinity balance.

Alkalinity to maintain pH ~ 7 = Influent Alk − Alk used + Alk to be added

Influent alkalinity : 150 mg/L as $CaCO_3$

Amount of nitrogen converted to nitrate : NO_x = 20.81 g/m^3

Alkalinity used for nitrification = $(7.14 \ g \ CaCO_3/g \ NH_3\text{-}N)(\cancel{28.3} \ 20.81 \ g/m^3)$

$= 148.58 \ g/m^3$ as $CaCO_3$

b). Substitute known values and solve for alkalinity needed.

Residual alkalinity concentration needed to maintain pH in the range of 6.8 − 7.0 = 70 to 80 g/m^3 as $CaCO_3$; select 80 g/m^3.

$80 \ g/m^3$ = Influent alk − alk used + alk to be added

80 = 150 − 148.58 + alk to be added.

Alkalinity needed = 78.58 g/m^3 as $CaCO_3$

$= (1000 \ m^3/d) \times (78.58 \ g/m^3) \times 10^{-3} \ kg/g$

$= 78.58$ kg/d. as $CaCO_3$

c). Determine the alkalinity needed as sodium bicarbonate

Sodium bicarbonate may be preferred over lime for alkalinity addition due to ease of handling and fewer scaling problems as compared to lime. The amount of $Na(HCO_3)$ needed is as follows:

Eq. weight of $CaCO_3$ = 50 g/equivalent.

Eq. weight of $NaHCO_3$ = 84 g/equivalent.

$$NaHCO_3 \text{ needed} = \frac{(78.58 \text{ kg/d } CaCO_3)(84 \text{ g } NaHCO_3/eq)}{(50 \text{ g } CaCO_3/eq)}$$

$$= 132 \text{ kg/d as } NaHCO_3$$

Step 20: Estimate effluent BOD using Eq. (8-25)

$$BOD = sBOD_e + \left(\frac{g\ BOD}{1.42 g\ VSS}\right)\left(\frac{0.85 g\ VSS}{g\ TSS}\right)(TSS,\ g/m^3)$$

Assume $sBOD_e = 3.0\ g/m^3$

$TSS = 10\ g/m^3$

$BOD = 3.0\ g/m^3 + 0.7 \times 0.85 \times 10$

$= 8.95\ g/m^3$.

Step 21: Secondary clarifier design (for both BOD removal and BOD & nitrification)

a). Define return sludge cycle ratio

$Q_r X_r = (Q + Q_r) X$ (assume waste sludge mass is insignificant)

Q_r = RAS flowrate, m^3/d

X_r = return sludge mass concentration, g/m^3.

RAS recycle ratio = $Q_r/Q = R$

$$R X_r = (1+R) X$$

$$R = \frac{X}{X_r - X}$$

b). Determine the size of clarifier,

Assume X_r = 8000 g/m³ (moderate settling / thickening sludge ; per sec. 8-8 range is 4000–12000 mg/L)

$$R = \frac{3000 \text{ mg/L}}{(8000 - 3000) \text{ mg/L}} = 0.60$$

Assuming a hydraulic application rate of 22 m³/m²·d at average flow for the secondary clarifier ; the range is 16 to 28 m³/m²·d

$$\text{Area} = \frac{1000 \text{ m}^3/\text{d}}{22 \text{ m}^3/\text{m}^2 \cdot \text{d}} = 45.45 \text{ m}^2$$

Area / clarifier = 45.45 m² (1 clarifier for 1 tank)

clarifier diameter = 7.6 m ; use 8 m.

c). check solids loading

$$\text{solids loading} = \frac{\text{kg TSS applied}}{\text{m}^2 \text{ clarifier area} \cdot \text{h}}$$

$$\text{solids loading} = \frac{(Q + Q_r)\,\text{MLSS}}{A} = \frac{(1+R)\,Q\,(\text{MLSS})}{A}$$

where, A = area of clarifier, m² $= (\pi/4)(8 \text{ m})^2 \times 1$

$= 50.26 \text{ m}^2$

$$\text{solids loading} = \frac{(1+0.6)(1000 \text{ m}^3/\text{d})(3000 \text{ mg/L} \ \text{g/m}^3)(1 \text{ kg}/10^3 \text{ g})}{50.26 \text{ m}^2 \times 24 \text{ h/d}}$$

$= 3.98$ MLSS/m²·h

~ 4 MLSS/m²·h

(within acceptable range of solids loading of 4 – 6 kg/m²·h given in Table 8-7)

Step 22: Prepare design summary.

DESIGN SUMMARY

Design Parameter	Unit	BOD removal only (Part A)	BOD removal and nitrification (part B)
1). Average wastewater flow	m^3/d	1000	1000
2). Average BOD load	kg/d	200	200
3). Average TKN load	kg/d	30	30
4). Aerobic SRT	d	5	12.5
5). Aeration tanks.	Number	2	2
6). Aeration tank volume, ea	m^3	110	240
7). Hydraulic detention time, τ	h	5.27	11.52
8). MLSS	g/m^3	3000	3000
9). MLVSS	g/m^3	2460	2400
10). F/M	g/g.d	0.37	~~0.42~~ 0.17
11). BOD loading	kg BOD/m^3.d	0.91	0.42
12). Sludge production	kg/d	131.79	~~12.78~~ 115.21
13) observed yield	kgTSS/ kg bCOD	0.414	0.36
	kg VSS/kg BOD	0.54	0.46
14). Oxygen required	kg/h	7.68	12.76
15). Air flow rate at avg. wastewater flow	sm^3/min.	3.53	4.524
16). RAS ratio	unitless	0.6	0.6
17). clarifier hydraulic application rate	$m^3/m^2.d$	22	22
18). Clarifiers	Number	2	2
	Diameter, m	8	8

19). Alkalinity addition as $Na(HCO_3)$	kg/d	—	132
		<30	8.95
20). Effluent BOD	g/m^3		
		<30	10
21). TSSe	g/m^3		
22). Effluent NH_4-N	g/m^3.	28.8	≤0.5