

CSTR with cell recycle

Example of Oxygen-supply and suspended solids-constrained design

CONSTRAINTS

rate of O_2 supply $\leq 1,200 \text{ mg } O_2/\text{l} \cdot \text{d}$

Maximum MLVSS = $2,500 \text{ mg VSS/l}$

Operating information

$$S_{SO} = 250 \text{ mg/l COD}$$

$$Q = \frac{1 \text{ m}^3}{5} = 86400 \frac{\text{m}^3}{\text{d}}$$

$$S_S < 25 \text{ mg/L COD}$$

$$S_{NH_4} = 40 \text{ mg/L } NH_4\text{-N}$$

Kinetic and stoichiometric data

$$\hat{\mu}_H = 4 \text{ d}^{-1}, \quad \hat{\mu}_A = 1 \text{ d}^{-1}$$

$$K_S = 25 \text{ mg COD/l}, \quad K_{NH} = 3 \text{ mg N/l}$$

$$b_H = b_A = 0.05 \text{ d}^{-1}$$

$$Y_H = 0.64 \text{ g COD}_X/\text{g COD}_S, \quad Y_A = 0.12 \text{ g COD}_X/\text{g } NH_4\text{-N}$$

$$f_D = 0.2 \text{ g debris/g COD decayed}$$

$$i_{NXB} = 0.09 \text{ g } NH_4\text{-N/g COD}_X$$

$$\mu_H = \frac{\hat{\mu}_H S_S}{K_S + S_S}$$

$$\mu_A = \frac{\hat{\mu}_A S_{NH}}{K_{NH} + S_{NH}}$$

Procedure

for $0.5 < \theta < 25$ (column 1)

compute
COD oxidation

$$(2) \quad S_s = \frac{K_s(1+b\theta)}{\hat{\mu}_H\theta - (1+b\theta)} \quad (\text{mg/l COD})$$

$$(3) \quad X_{BH} * \tau = \frac{Y_H \theta (S_{s0} - S_s)}{(1+b\theta)} \quad (\text{mg COD} \times \text{d/l})$$

$$(4) \quad X_D * \tau = \frac{f_D b \theta^2 (Y_H (S_{s0} - S_s))}{(1+b\theta)} \quad (\text{mg COD} \times \text{d/l})$$

$$(5) \quad X_T * \tau = X_{BH} * \tau + X_D * \tau \quad ((\text{mg COD} \times \text{d})/\text{l})$$

$$(6) \quad Y_{Hobs} = Y_H \frac{(1+f_D b \theta)}{(1+b\theta)} \quad \left(\frac{\text{g COD}_x}{\text{g COD}_s} \right)$$

$$(7) \quad W_T = Q (Y_{Hobs} (S_{s0} - S_s)) / 1.42 / 10^3 \quad (\text{kg VSS/d})$$

$$(8) \quad X_{NH, cells} = i_{NXB} Y_{Hobs} (S_{s0} - S_s) \quad (\text{neglect } X_{BA}) \quad (\text{mg N/l})$$

$$(9) \quad \text{calculate } \tau_{min} = \frac{1}{1200} [(1 - Y_{Hobs}) (S_{s0} - S_s)] \quad (\text{d})$$

where $1200 \frac{\text{mg O}_2}{\text{l} \cdot \text{d}} = R_{O \max}$

$$(10) \quad X_{Tmax} = X_T * \tau / \tau_{min} \quad (\text{mg COD/l} / 1.42) \Rightarrow (\text{mg VSS/l})$$

$$(11) \quad X_{BHmax} = X_{BH} * \tau / \tau_{min} / 1.42 \quad (\text{mg VSS/l})$$

$$(12) \quad X_{Dmax} = X_D * \tau / \tau_{min} / 1.42 \quad (\text{mg VSS/l})$$

$$(13) \quad V_{min} = Q \tau_{min} \quad (\text{m}^3)$$

note for τ_{min} and $\theta \geq 2d$ MLVSS exceeds
constraint

recalculate

3

(14) V for $X_T \leq 2500 \text{ mgVSS/l}$

$$(\text{new}) V = (X_T * \tau / 2500 / 1.42) * 86400 \text{ (m}^3\text{)}$$

(note $\theta \leq 3 \text{ d}$ excluded to maintain 2500)

(15) recalculate $RO_{\text{COD}} = \frac{Q}{V} \left[(1 - Y_{\text{tobs}}) * (S_{\text{so}} - S_s) \right]$
for $\theta > 3 \text{ d}$ (mgO₂/l/d)

(16) $\text{new } \tau = \frac{\text{new } V}{Q}$

nitrification

(17) $S_{\text{NH}} = \frac{K_{\text{NH}}(1 + b\theta)}{\hat{\mu}_A\theta - (1 + b\theta)}$ (mgN/l)

(18) $X_{\text{BA}}^* \tau = \frac{\theta Y_A (S_{\text{NH}_0} - X_{\text{NHcells}} - S_{\text{NH}})}{(1 + b\theta)}$ (mgCOD·d/l)

(19) $X_{\text{BA}} = \frac{X_{\text{BA}}^* \tau}{\text{new } \tau}$ (mgCOD_{XA}/l) / 1.42 = (mgVSS/l)

(20) $RO_{\text{NH}} = \frac{4.57}{\text{new } \tau} (S_{\text{NH}_0} - X_{\text{NHcells}} - S_{\text{NH}})$ (mgO₂/l/d)

(21) $RO_{\text{TOTAL}} = RO_{\text{COD}} + RO_{\text{NH}}$ (mgO₂/l/d)

check to see if $RO_{\text{TOTAL}} < 1200 \text{ mgO}_2/\text{l/d}$
if YES, V must be increased for that θ

for $\text{COD}_{\text{eff}} < 25 \text{ mg/L}$, $\theta \geq 1 \text{ d}$.

for $\text{NH}_4\text{-N}_{\text{eff}} < 1 \text{ mg/L}$, $\theta \geq 8 \text{ d}$

select $\theta = 8 \text{ d}$ for minimum $V = 24,000 \text{ m}^3$

$S_s = 1.1 \text{ mgCOD/l}$ ✓

$X_T = 2500 \text{ mgVSS/l}$

$RO_T = 916 \text{ mgO}_2/\text{l/d}$ ✓

$W_T = 7.5 \text{ MT/d}$

$f_A = \frac{X_{\text{BA}}}{X_T} = \frac{910 / 1.42 / 0.28}{2500} = 0.92$

OTHER possible constraints

4

S_{smin} and S_{NHmin} ($\mu \rightarrow b$) (starvation)

$$S_{smin} = \frac{K_s b}{\hat{\mu}_H - b} = \frac{25(0.05)}{4 - 0.05} = 0.3 \text{ mgCOD/l} \checkmark$$

$$S_{NHmin} = \frac{K_{NH} b}{\hat{\mu}_A - b} = \frac{3(0.05)}{1 - 0.05} = 0.16 \text{ mgN/l} \checkmark$$

θ_{amin} for X_{BA} (washout), $S_{NH} \rightarrow S_{NH0} - X_{NH}$
for $X_{NH} = 12 \text{ mgN/l}$

$$\theta_{amin} = \frac{K_{NH} + (S_{NH0} - X_{NH})}{(S_{NH0} - X_{NH})(\hat{\mu}_A - b) - K_{NH} b}$$

(theoretical)

$$= \frac{3 + (40 - 12)}{(40 - 12)(1 - 0.05) - 3(0.05)} = 1.17 \text{ d} \checkmark$$

Actual $\theta > 4 \text{ d}$

Also typically $\theta > 3 \text{ d}$ for flocculation