CSTR with cell recycle

Example of Oxygen-supply and suspended solids-constrained design

CONSTRAINTS

rate of O_2 supply $\leq$ 1,200 mg-O_2/l·d

Maximum MLVSS = 2,500 mg VSS/l

Operating information

$S_{S0} = 250$ mg/l COD $\qquad Q = 1 \frac{m^3}{s} = 86400 \frac{m^3}{d}$

$S_S < 25$ mg/L COD

$S_{NH0} = 40$ mg/L NH_4-N

Kinetic and stoichiometric data

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

$K_S = 25$ mgCOD/l, $K_{NH} = 3$ mgN/l

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

$Y_H = 0.64$ gCODx/gCODs, $Y_A = 0.12$ gCODx/gNH_4-N

$f_D = 0.2$ g debris/gCOD decayed

$i_{NXB} = 0.09$ gNH_4-N/gCODXB

$$\mu_H = \frac{\hat{\mu}_H S_S}{K_S + S_S} \qquad \mu_A = \frac{\hat{\mu}_A S_{NH}}{K_{NH} + S_{NH}}$$

Procedure

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

compute

COD oxidation

② $S_S = \frac{K_S(1+b\Theta)}{\hat{\mu}_H\Theta-(1+b\Theta)}$ (mg/l COD)

③ $X_{BH}*\tau = \frac{Y_H\Theta(S_{S0}-S_S)}{(1+b\Theta)}$ (mg CODx·d/l)

④ $X_D*\tau = f_D b \frac{\Theta^2(Y_H(S_{S0}-S_S))}{(1+b\Theta)}$ (mg CODx·d/l)

⑤ $X_T*\tau = X_{BH}*\tau + X_D*\tau$ ((mg CODx·d)/l)

⑥ $Y_{Hobs} = Y_H\frac{(1+f_D b\Theta)}{(1+b\Theta)}$ $\left(\frac{g\,CODx}{g\,CODs}\right)$

⑦ $W_T = Q(Y_{Hobs}(S_{S0}-S_S))/1.42/10^3$ (kg VSS/d)

⑧ $X_{NH,cells} = i_{NXB}\, Y_{Hobs}(S_{S0}-S_S)$ (neglect X_{BA}) (mgN/l)

⑨ calculate $\tau_{min} = \frac{1}{1200}\left[(1-Y_{Hobs})(S_{S0}-S_S)\right]$ (d)

where $1200\ \frac{mg\,O_2}{l\cdot d} = RO_{max}$

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

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

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

⑬ $V_{min} = Q\,\tau_{min}$ (m^3)

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

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

(new) $V = (X_T * Q / 2500 / 1.42) * 86400$ (m^3)

(note $\Theta \leq 3d$ excluded to maintain 2500)

(15) recalculate $RO_{COD} = \frac{Q}{V}\left[(1 - Y_{Htobs}) * (S_{so} - S_s)\right]$ ($mgO_2/l/d$)

for $\Theta > 3d$

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

nitrification

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

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

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

(20) $RO_{NH} = \frac{4.57}{\text{new } \tau}(S_{NHo} - X_{NHcells} - S_{NH})$ ($mgO_2/l/d$)

(21) $RO_{TOTAL} = RO_{COD} + RO_{NH}$ ($mgO_2/l/d$)

check to see if $RO_{TOTAL} < 1200$ $mgO_2/l/d$
if YES, V must be increased for that Θ

for $COD_{eff} < 25$ mg/L, $\Theta \geq 1d$.

for NH_4-$N_{eff.} < 1$ mg/L, $\Theta \geq 8d$

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

$S_s = 1.1$ mgCOD/l ✓

$X_T = 2500$ mgVSS/l $f_A = \frac{X_{BH}}{X_T} = \frac{910/1.42/0.28}{2500} = 0.92$

$RO_T = 916$ $mgO_2/l/d$ ✓

$W_T = 7.5$ MT/d

OTHER possible constraints

$S_{S\,min}$ and $S_{NH\,min}$ $\left(\hat{\mu} \to b\right)$ $\left(1/\theta \to 0\right)$ (starvation)

$$S_{S\,min} = \frac{K_S b}{\hat{\mu}_H - b} = \frac{25(0.05)}{4-0.05} = 0.3 \text{ mgCOD/l} \checkmark$$

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

θ_{min} for X_{BA} (washout), $S_{NH} \to S_{NHo} - X_{NH}$ for $X_{NH} = 12$ mgN/l

θ_{min} (theoretical)

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

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

Actual $\theta > 4$ d

Also typically $\theta > 3$ d for flocculation