Objectives

- Determine various parameters for a complete-mix activated sludge process.
- Perform a materials balance around a sludge thickening process.

Activated Sludge Example

- A CMAS is to be designed to treat 6.0 MGD of domestic wastewater having a BOD$_5$ of 250 mg/L.
- The effluent BOD$_5$ and TSS concentrations should be 20 mg/L or less on an annual average basis.
- The following biokinetic coefficients obtained at 20°C will be used in designing the process: $Y = 0.6$ mg VSS/mg BOD$_5$, $k = 5$ d$^{-1}$, $K_I = 60$ mg/L, BOD$_5$, and $K_d = 0.06$ d$^{-1}$.
- MLVSS concentration=3000 mg/L
- VSS:TSS ratio is 0.80.
- Temperature of the wastewater during the winter months is expected to remain at 18°C for extended periods.
- During the summer, the wastewater temperature may reach 35°C for several weeks.
Activated Sludge Example 2

- Determine the following:
  - Effluent soluble BOD\(_5\) (SBOD\(_5\)) concentration.
  - MCRT necessary to meet permit during the winter.
  - Volume of the aeration basin in cubic feet.
  - MCRT necessary to meet permit during the summer.
  - Oxygen required during the summer assuming no nitrification.
  - Quantity of biomass produced in terms of TSS at the shortest MCRT that the facility will be operated.

Effluent Particulate BOD

\[
PBOD_5 = VSS_e \cdot 1.42 \left( \frac{2}{3} \right)
\]

\[
VSS_e = \left( \frac{VSS}{TSS} \right) TSS_e = 0.80 \times 20 \text{ mg/L} = 16 \text{ mg/L}
\]

\[
PBOD_5 = \left( \frac{16 \text{ mg/L}}{L} \right) 1.42 \left( \frac{2}{3} \right) = 15.1 \text{ mg/L}
\]

Effluent Soluble BOD

\[
TBOD_5 = PBOD_5 + SBOD_5
\]

\[
SBOD_5 = TBOD_5 - PBOD_5
\]

\[
SBOD_5 = 20 - 15.1 = 4.9 \text{ mg/L}
\]
Correct Biokinetic Coefficients for Winter Temperature

\[ K_2 = K_1 \theta^{T_2 - T_i} \]

\[ k_{18°C} = 5 \text{ d}^{-1} \quad 1.07 \quad 18°C \rightarrow 20°C = 4.4 \text{ d}^{-1} \]

\[ K_{r_{18°C}} = 60 \quad \frac{\text{mg}}{\text{L}} \quad 1.00 \quad 18°C \rightarrow 20°C = 60 \quad \frac{\text{mg}}{\text{L}} \]

\[ k_d_{18°C} = 0.06 \text{ d}^{-1} \quad 1.04 \quad 18°C \rightarrow 20°C = 0.06 \text{ d}^{-1} \]

Develop Equation for MCRT

\[ \left( \frac{dX}{dt} \right)_{wG} = \frac{Q - Q_s X}{X + X_s} + Q_s X_s = \frac{1}{\theta_e} \cdot \frac{dS}{dt} = \frac{dX}{dt} - k_d \]

\[ \left( \frac{dS}{dt} \right)_{V} = \frac{k X S_e}{K_s + S_e} \]

Calculate Winter MCRT

\[ \frac{1}{\theta_e} = Y \cdot \frac{dS}{dt} = \frac{dX}{dt} - k_d = Y \left( \frac{k S_e}{K_s + S_e} \right) - k_d \]

\[ \frac{1}{\theta_e} = \frac{0.6 \text{ mg VSS}}{60 \quad \text{mg BOD}_5} \left( \frac{4.4 \text{ d}^{-1}}{60 \quad \text{mg BOD}_5 + 4.9 \quad \text{mg VSS}} \right) = 0.06 \quad \text{d}^{-1} = 0.14 \quad \text{d}^{-1} \]

\[ \theta_e = \frac{1}{0.14 \quad \text{d}^{-1}} = 7.1 \text{ d} \]
Design MCRT for Winter

Typically, a safety factor of 2 to 10 is applied to the calculated MCRT to obtain the design MCRT.

\[ \theta_{\text{design}} = \text{Safety Factor} \times \theta_c \]

Not necessary to use a safety factor since the MCRT is greater than 5 days which is the typical value at which nitrification occurs at 20°C.

Check Effluent Substrate Concentration in Winter

\[ S_e = \frac{K_Y}{\theta_c} \frac{1 + k_d \theta_c}{Y k - k_d} - 1 \]

\[ S_e = \frac{60 \text{ mg L}^{-1} + 0.06 \text{ d}^{-1} \times 7.1 \text{ d}}{7.1 \text{ d} \left( \frac{0.6 \text{ g VSS}}{\text{g BOD}_5} \times 4.4 \text{ d}^{-1} - 0.06 \text{ d} \right)} = 4.9 \text{ mg L}^{-1} \]

Volume of Aeration Basin

\[ \psi = \frac{Y Q}{1 + k_d \theta_c} \frac{S_i - S_e}{X} \]

\[ \psi = \frac{0.60 \text{ mg VSS}}{\text{mg BOD}_5} \left( \frac{6.0 \times 10^8 \text{ gal}}{1} \right) \left( \frac{250 \text{ mg L}^{-1}}{1} - \frac{4.9 \text{ mg L}^{-1}}{1} \right) \frac{7.1 \text{ d}}{1 + 0.06 \text{ d}^{-1} \times 7.1 \text{ d}} = 1.46 \times 10^6 \text{ gal} \]

\[ \psi = 1.46 \times 10^6 \text{ gal} \left( \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \right) = 1.95 \times 10^3 \text{ ft}^3 \]
Correct Biokinetic Coefficients for Summer Temperature

\[ K_2 = K_1 \theta^{\frac{T_2 - T_i}{T_2 - T_i}} \]
\[ k_{18^\circ C} = 5 \, \text{d}^{-1} \times 1.07 \times 25^\circ C - 20^\circ C = 7.0 \, \text{d}^{-1} \]
\[ K_{s_{18^\circ C}} = 60 \, \text{mg L}^{-1} \times 1.00 \times 25^\circ C - 20^\circ C = 60 \, \text{mg L}^{-1} \]
\[ k_{d_{18^\circ C}} = 0.06 \, \text{d}^{-1} \times 1.04 \times 25^\circ C - 20^\circ C = 0.07 \, \text{d}^{-1} \]

Calculate Summer MCRT

\[ \frac{1}{\theta_e} = Y \frac{dS/dt}{X} - k_d = Y \left( \frac{k}{K_s + S_e} - k_d \right) \]
\[ \theta_e = \frac{1}{0.25 \, \text{d}} = 4.0 \, \text{d} \]

Effluent Substrate Concentration in Summer

\[ S_e = \frac{K_s \times 1 + k_d \theta_e}{\theta_e \times Y \left( k - k_d \right) - 1} \]
\[ S_e = \frac{60 \, \text{mg L}^{-1} \times 1 + 0.07 \, \text{d}^{-1} \times 4 \, \text{d}}{4 \, \text{d} \left( 0.6 \, \text{g VSS} / \text{g BOD}_5 \times 7.0 \, \text{d}^{-1} - 0.07 \, \text{d} \right) - 1} = \frac{4.9 \, \text{mg L}^{-1}}{4.9 \, \text{mg L}^{-1}} \]
Detention Time

$$\theta = \frac{V}{Q}$$

$$\theta = \frac{V}{Q} = \frac{1.46\text{MG}}{6.0\text{MGD}} = 0.24\text{d}$$

Biomass Concentration in Summer

$$X = \frac{Y \left( S_i - S_c \right)}{1 + k_d \theta_c \theta}$$

$$X = \frac{0.60\text{mg VSS}}{1 + 0.07\text{d}^{-1} \times 4.0\text{d}} \times \frac{\left( 250\text{mg L}^{-1} - 4.9\text{mg L}^{-1} \right)}{4.0\text{d}}$$

$$X = \frac{1915\text{mg VSS}}{L}$$

Oxygen Requirements

$$O_2 = Q \left( S_i - S_c \right) \left( 1 - 1.42Y + 1.42k_d X \right) \Psi + \text{NOD}$$

$$O_2 = \frac{[6.0\text{MG d}^{-1} \times 250 - 4.9\text{mg L}^{-1} \times (1 - 1.42 \times 0.60\text{mg VSS mg BOD}_{5}^{-1})]}{1.42 \times 0.06\text{d}^{-1} \times \frac{3000\text{mg L}^{-1} \times 1.46\text{MG} + 0}{3000\text{mg L}^{-1}} + \frac{8.34\text{lb}}{\text{MG} \times \text{mg L}^{-1}}}$$

$$O_2 = \frac{4927\text{ lb O}_2}{\text{d}}$$
Biomass Production Occurs at Lowest MCRT

\[ P_x = \frac{Y Q S_i - S_v}{1 + k_d \theta_c} \]

\[ P_x = \frac{Y Q S_i - S_v}{1 + k_d \theta_c} = \frac{0.60 \text{ mg VSS}}{\text{mg BOD}_5} \cdot \frac{6.0 \text{ MGD}}{250 \text{ mg L}^{-1}} \cdot \left( \frac{4.9 \text{ mg L}^{-1}}{8.34 \text{ lb} \text{ mg}^{-1}} \right) \]

Biomass Production 2

\[ P_x = 5750 \frac{\text{lb VSS}}{\text{d}} \]

\[ P_x = 5750 \frac{\text{lb VSS}}{\text{d}} \times \left( \frac{1 \text{ lb TSS}}{0.80 \text{ lb VSS}} \right) = 7190 \frac{\text{lb TSS}}{\text{d}} \]

GBT Design Example

- Design a GBT to thicken WAS from 1% to 5% solids and operate 5 days per week for 8 hours each day.
- 10,000 kg of WAS are produced daily.
- The SS concentration in the filtrate is 1000 mg/L.
- Use the following design criteria: hydraulic loading rate = 140 to 450 gpm/m (6.7 to 47 L/s) (Metcalf and Eddy, recommend 200 gpm/m or 800 L/(m·min));
- Solids loading rate = 370 to 1200 lb/(m·h) or 200 to 600 kg/(m·h).
- Washwater rate = 25 gpm/meter of belt (95 Lpm/m).
Calculate the daily solids loading rate to the GBT

\[ \frac{10,000 \text{ kg}}{\text{d}} \left( \frac{7 \text{ d}}{\text{wk}} \right) \left( \frac{1 \text{ wk}}{5 \text{ d}} \right) \left( \frac{1 \text{ d}}{8 \text{ h}} \right) = \frac{1750 \text{ kg}}{\text{h}} \text{ or } \frac{14,000 \text{ kg}}{\text{d}} \]

Sludge volume entering the GBT

\[ \phi = \frac{W_s}{S \cdot s/100} \]

\[ \phi = \frac{14,000 \text{ kg/d}}{1.00 \cdot 1000 \text{ kg/m}^3 \cdot 1/100} = 1400 \text{ m}^3/\text{d} \text{ or } 2916 \text{ Lpm} \]
Determine Belt Width

\[
\text{belt width} = \frac{2916 \text{ Lpm}}{800 \text{ Lpm/m}} = 3.6 \text{ m}
\]

Use two, 2.0-m belts.

Check solids loading rate

\[
\text{solids loading rate} = \frac{1750 \text{ kg/h of solids}}{2 \times 2 \text{ m}} = 438 \text{ kg/m} \cdot \text{h}
\]

This is acceptable since the SLR design criteria specify 200 to 600 kg/(m·h).

Determine the sludge cake and filtrate flows

\[
Q_{\text{sludge}} + Q_{\text{washwater}} = Q_F + Q_C
\]

\[
2916 \text{ Lpm} + 2 \times 2 \text{ m} \times 95 \text{ Lpm/m} = Q_F + Q_C
\]

\[
3296 \text{ Lpm} = Q_F + Q_C
\]
Determine the sludge cake and filtrate flows

\[ 3296 \text{ L} \text{ min}^{-1} \left( \frac{60 \text{ min}}{\text{ h}} \right) \left( \frac{8 \text{ h}}{\text{ d}} \right) \left( \frac{\text{ m}^3}{1000 \text{ L}} \right) = 1582 \text{ m}^3 \text{ d}^{-1} \]

\[ 1582 \frac{\text{ m}^3}{\text{ d}} = Q_F + Q_C \]

\[ Q_C = 1582 \frac{\text{ m}^3}{\text{ d}} - Q_F \]

Perform a mass balance on solids

\[ M_{\text{sludge}} = M_C + M_F \]

\[ 14,000 \text{ kg/d} = Q_F \left( 5 \times 10,000 \frac{\text{ g}}{\text{ m}^3} \right) \left( \frac{1 \text{ kg}}{1000 \text{ g}} \right) + Q_F \left( 1000 \frac{\text{ g}}{\text{ m}^3} \right) \left( \frac{1 \text{ kg}}{1000 \text{ g}} \right) \]

\[ 14,000 \text{ kg/d} = 50 Q_C + 1.0 Q_F \]

Perform a mass balance on solids 2

\[ 14,000 \text{ kg/d} = 50 \left( 1582 \frac{\text{ m}^3}{\text{ d}} - Q_F \right) + 1.0 Q_F \]

\[ 49 Q_F = 65,100 \]

\[ Q_F = 1329 \frac{\text{ m}^3}{\text{ d}} \text{ or } 2769 \text{ Lpm} \]
**Cake Flow**

\[ Q_c = 1582 \, \text{m}^3/\text{d} - Q_f = 4329 \, \text{m}^3/\text{d} \]

\[ Q_c = 253 \, \text{m}^3/\text{d} \text{ or } 527 \, \text{Lpm} \]

**Solids in Filtrate**

\[ 1329 \, \text{m}^3/\text{d} \left( 1000 \, \text{g}/\text{m}^3 \right) \left( \frac{1 \, \text{kg}}{1000 \, \text{g}} \right) = 4329 \, \text{kg}/\text{d} \]

**Percent Capture**

\[ \% \, \text{Capture} = \frac{\text{solids in feed} - \text{solids in filtrate}}{\text{solids in feed}} \times 100 \]

\[ \% \, \text{Capture} = \frac{14,000 \, \text{kg/d} - 4329 \, \text{kg/d}}{14,000 \, \text{kg/d}} \times 100 \% = 90.5 \% \]
Final Mass Balance

- **Washwater**
  - Sludge feed
    - 1% Solids
      - 14,000 kg/d
      - 2916 Lpm
      - 1,000 mg/L

- **GBT**
  - Filtrate
    - 9% Solids
      - 380 Lpm
    - 5% Solids
      - 1329 kg/d
      - 2769 Lpm

- **Sludge cake**
  - 6% Solids
    - 12,671 kg/d
    - 527 Lpm

- **Filtrate**
  - 0% Solids
    - 380 Lpm

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