Biological Wastewater Treatment

CE 326 Principles of Environmental Engineering
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Announcements

• Wednesday lab
  – In 2nd floor classroom (230 & 250 TEB)
• Chapter 6 practice problems (to review in class on Friday):
  – 6:18
  – 6:26
• Wednesday - BOD & TSS lab due
• Friday - Ames UPoF write-up
Activated Sludge

Monod

\[ \mu = \frac{\mu_{\text{max}} S}{K_S + S} \]

- \( \mu \): specific growth rate, \( \text{h}^{-1} \)
- \( \mu_{\text{max}} \): maximum specific growth rate, \( \text{h}^{-1} \)
- \( K_S \): half-saturation coefficient, \( \text{mg/L as BOD}_5 \)
- \( S \): substrate concentration, \( \text{mg/L as BOD}_5 \)

Minimize effluent \( \text{BOD}_5 \)
\[ \begin{align*}
Q, X_0, S_0 & \quad \text{influent, recycled} \\
Qr, X_r, S & \quad \text{waste flow rates, m}^3/\text{d} \\
V & \quad \text{volume of aeration basin, m}^3 \\
X_0, X, X_e, X_r & \quad \text{biomass concentrations in influent, aeration basin, effluent & recycle, mg/L as VSS} \\
S_0, S & \quad \text{influent & effluent substrate conc. BOD, mg/L} 
\end{align*} \]
Biomass mass balance:

\[ \text{in} - \text{out} + \text{generation} = 0 \quad \text{at steady state} \quad x_w = x_r \]

\[ QX_0 + A \left( \mu X - kd X \right) = (Q - Q_w)X_e + Q_wX_w \]

\( QX_0 \) = in + generation

\( A \) = out

\( V \) = volume of generation basin

\( \mu = \frac{m_{max} S}{K_S + S} \) = specific growth rate

\( kd \) = decay coefficient, \( h^{-1} \)

\[ QX_0 + A \left( \frac{m_{max} S X}{K_S + S} - kd X \right) = (Q - Q_w)X_e + Q_wX_w \]

\( m_{max} \) = maximum growth rate

\( K_S \) = half-saturation constant

\( S \) = substrate concentration

\( X \) = biomass concentration
Substrate Mass balance

\[ Q S_0 - H \left( \frac{V_{max} \cdot S \cdot X}{(k_S + S) \cdot Y} \right) = (Q - Q_w)S + Q_w S \]

\( Y = \) yield coefficient, mg VSS formed/mg BODs consumed

3 simplifying assumptions

1. Influent and effluent biomass concentration is negligible.
2. Aeration basin is a perfect CSTR (continuous stirred tank reactor).
3. All reactions occur in aeration basin.
Biomass:

\[ \frac{M_{\text{max}} S}{K_s + S} = \frac{Q_w X_w}{V X} + 1_d \]

\[ S = \frac{K_s}{\Theta_c} \left( 1 + 1_d \Theta_c \right) \]

\[ \Theta = \text{hydraulic retention time, h} \]

\[ \Theta_c = \text{solids retention time, h} \]

Substrate:

\[ \frac{M_{\text{max}} S}{K_s + S} = \frac{Q Y}{V X} (S_o - S) \]

\[ \Theta = \frac{V}{Q} \]

\[ \Theta_c = \frac{V X}{Q_w X_w} \text{ - mass of solids in system} \]

\[ X = \frac{\Theta_c Y (S_o - S)}{\Theta (1 + 1_d \Theta_c)} \]
Ex. Effluent permit of 20 mg/l BOD\(_5\) and 20 mg/l SS

\[ S_0 = 250 \text{ mg/l BOD}_5 \]

\[ \mu_{max} = 0.15 \text{ h}^{-1} \]

\[ K_s = 75 \text{ mg/l} \]

\[ h_d = 0.004 \text{ h}^{-1} \]

\[ Y = 0.5 \text{ mg VSS/mg BOD}_5 \]

\[ \text{BOD}_5 \text{ of SS} = 0.65 \]

\[ S = \frac{K_s(1 + h_d \Theta_c)}{\Theta_c(\mu_{max} - K_d) - 1} \]

\[ T = \frac{K_s + S}{S(\mu_{max} - K_d) - K_s h_d} = \frac{75 + 7}{7(0.15 - 0.004) - 75(0.004)} = 113.5 \text{ h} \approx 5 \text{ d} \]

if we discharge 20 mg/l SS

\[ 20(0.65) = 13 \text{ mg/l BOD}_5 \]

\[ 20 + 13 = 33 \text{ mg/l of soluble BOD}_5 \]

leaves us 7 mg/l

we base our design around
\[ X = \frac{\Theta_c Y (S_0 - S)}{\Theta (1 + h d \Theta_c)} \]

Either assume \( X \)
or assume \( \Theta \)

Let's assume \( \Theta = 4 \ h \)

\[ X = \frac{113.5 (0.5) (250 - 7)}{4 (1 + 0.004 (113.5))} = 2371 \text{ mg/l} \] (USS concentration)