Fundamentals of biological treatment III

Modeling suspended growth processes

- Use the mass balance technique
- Use the kinetic expressions that we have discussed

- We can set mass balance for two substances in the activated sludge system:

1) Biomass mass balance

$$V\frac{dX_a}{dt} = 0 - [(Q - Q^w){X_a}^e] - Q^w {X_a}^r + r_X V$$

2) Substrate mass balance

$$V\frac{dS}{dt} = QS^0 - QS + r_{su}V$$

Modeling suspended growth processes

- Solving the two mass balance equations, we get:

$$X_a = \left(\frac{SRT}{\tau}\right)\left[\frac{Y(S^0 - S)}{1 + b(SRT)}\right]$$

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

  - The effluent substrate (=our target!) concentration is a function of SRT and growth kinetic parameters
  - SRT is the only controllable variable
  - The effluent substrate concentration is **NOT** a function of influent concentration (but S^0 affects X)

Solids production

- Remember:
  - VSS = active biomass + α
  - TSS = active biomass + α + β
- **Daily production of total sludge** from the system
  - At steady state, the mixed liquor can be assumed as a homogeneous mixture of active biomass and other solids (→ same SRT applies to VSS and TSS!)

$$P_{X,VSS} = \frac{X_{VSS}V}{SRT}$$

$P_{X,VSS}$ = daily production of total sludge as VSS (g VSS/d)

X_{VSS} = total MLVSS concentration in aeration tank (g VSS/m^3)

$$P_{X,TSS} = \frac{X_{TSS}V}{SRT}$$

$P_{X,TSS}$ = daily production of total sludge as TSS (g TSS/d)

X_{TSS} = total MLSS concentration in aeration tank (g TSS/m^3)

Modeling solids production

- **Total MLVSS in the aeration tank, X_{VSS}**

$$X_{VSS} = X_a + X_i$$

X_i = nbVSS concentration in aeration tank (g VSS/m³)

→ Additional mass balance needed for nbVSS

$$V\frac{dX_i}{dt} = QX_i^{\,0} - \frac{X_i V}{SRT} + r_{X,i}V$$

$X_i^{\,0}$ = nbVSS concentration in influent (g VSS/m³)

$r_{X,i}$ = rate of nbVSS production from cell debris (g/m³-d)

At steady state:

$$X_i = \frac{X_i^{\,0}(SRT)}{\tau} + (f_d)(b)(X_a)(SRT)$$

Modeling solids production

Therefore,

$$X_{VSS} = \left(\frac{SRT}{\tau}\right)\left[\frac{Y(S^0 - S)}{1 + b(SRT)}\right] + (f_d)(b)(X_a)(SRT) + \frac{X_i{}^0(SRT)}{\tau}$$

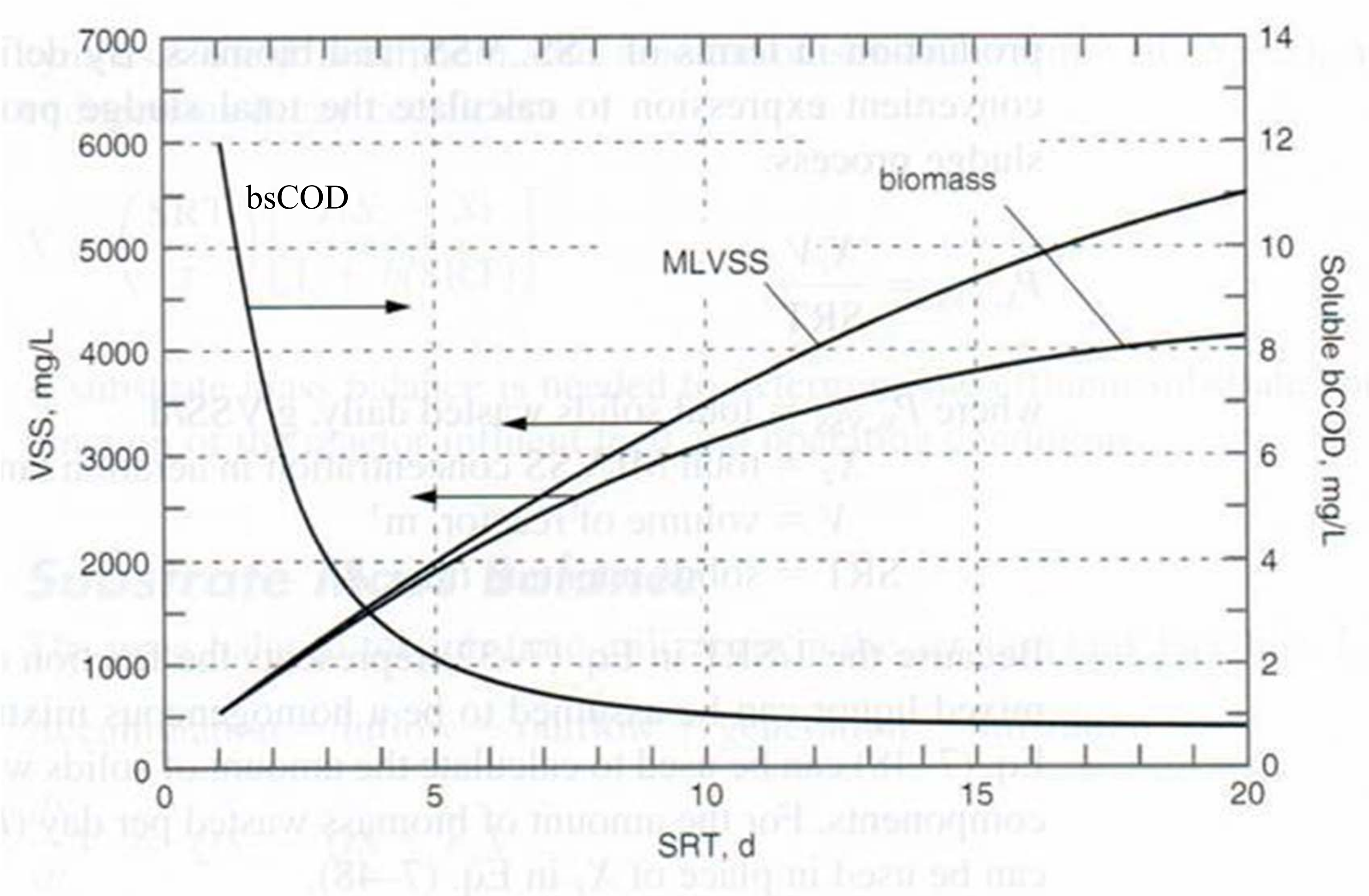
Active biomass *Cell debris* *nbVSS in influent*

The daily total VSS production (=wasted) rate, $P_{X,VSS}$ (g VSS/d):

$$P_{X,VSS} = \frac{QY(S^0 - S)}{1 + b(SRT)} + \frac{(f_d)(b)YQ(S^0 - S)SRT}{1 + b(SRT)} + QX_i{}^0$$

(A) ***(B)*** ***(C)***

Effect of SRT on bsCOD, biomass, and MLVSS



Modeling solids production

- **The daily MLSS (total dry solids) wasted**

  Note: TSS = VSS + FSS (inorganics)

  - Inorganic solids originate from influent and the biomass
  - Biomass contains 10-15% inorganic solids by dry weight
  - Use a VSS/TSS ratio of 0.85 for a typical biomass

$$P_{X,TSS} = \frac{(A)}{0.85} + \frac{(B)}{0.85} + C + Q\left(X_{TSS}{}^{0} - X_{VSS}{}^{0}\right)$$

$P_{X,TSS}$ = daily MLSSS produced per day (g TSS/d)

$X_{TSS}{}^{0}$ = influent wastewater TSS concentration (g/m^3)

$X_{VSS}{}^{0}$= influent wastewater VSS concentration (g/m^3)

Observed yield in the system

- Recall that the observed yield is:

(Amount of solids produced) / (Amount of substrates removed)

Therefore, for the observed yield of MLVSS,

$$Y_{obs} = \frac{P_{X,VSS}}{Q(S^0 - S)} = \frac{Y}{1 + b(SRT)} + \frac{(f_d)(b)(Y)SRT}{1 + b(SRT)} + \frac{{X_i}^0}{(S^0 - S)}$$

Oxygen requirements

- Additional matter of interest: **how much oxygen is needed (→ should be provided)** to support the aerobic biodegradation?
- Recall that by degradation of substrates:
  - some portion of the biodegradable COD (bCOD) is combined with O_2 to be mineralized or converted to oxidized organic compounds
- Some O_2 is also consumed for endogenous respiration

- Consider the COD mass balance of the system:

Oxygen used = (bCOD removed) – (COD of waste sludge)

$$R_o = Q(S_o - S) - 1.42P_{X,bio}$$

R_o = daily oxygen requirement (g/d)

*$P_{X,bio}$ = biomass as VSS wasted per day, **(A) + (B)** (g/d)*

Example question

Q: A complete-mix suspended growth activated sludge process with recycle is used to treat municipal wastewater after primary sedimentation. The characteristics of the primary effluent are: flow = 1000 m^3/d, bsCOD = 192 g/m^3, nbVSS = 30 g/m^3, and inert inorganics = 10 g/m^3. The aeration tank MLVSS is 2500 g/m^3. Using these data and the kinetics coefficients given below, design a system with a 6-d SRT and determine the following:

1) The effluent bsCOD concentration
2) Hydraulic retention time required
3) Daily sludge production (in kg/d as VSS and TSS)
4) Fraction of active biomass in the MLVSS
5) Observed solids yield (in g VSS/g bsCOD and g TSS/g bsCOD)
6) Oxygen requirement (in kg/d)

$k = 12.5\ g\ COD/g\ VSS - d$ $\quad\quad$ $K_s = 10\ g\ COD/m^3$

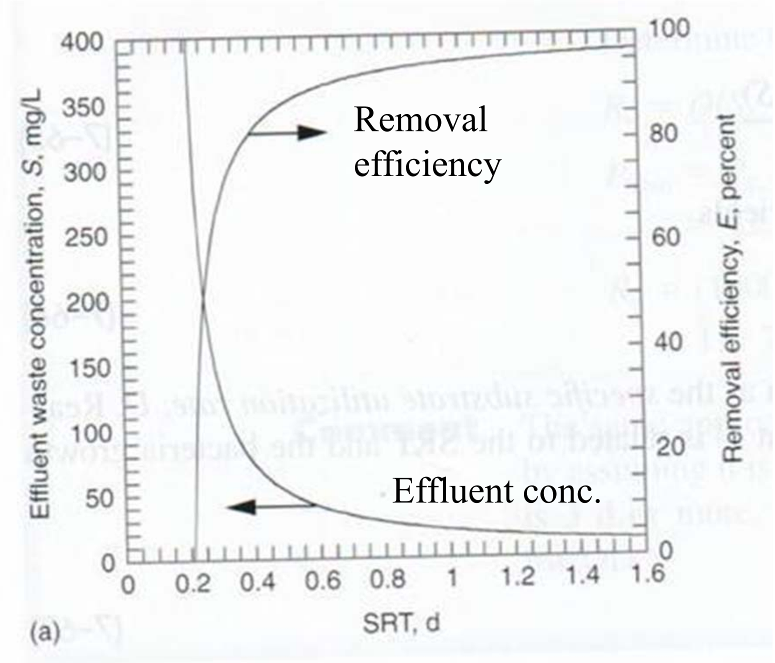
$Y = 0.40\ g\ VSS/g\ COD$ $\quad\quad$ $f_d = 0.15$

$b = 0.10\ /d$ $\quad\quad$ $Biomass\ VSS/TSS = 0.85$

Design & operating parameters

- **SRT: key variable**
  - When kinetic coefficients are fixed, the effluent concentration is solely a function of SRT

- Effluent concentration as a function of SRT



For CSTR with recycle

Design & operating parameters

- **The minimum solids retention residence time, *SRT_{min}***
  - The SRT at which the cells are washed out from the system faster than they can reproduce

$$\frac{1}{SRT_{min}} = \frac{YkS^0}{K_s + S^0} - b$$

  - In many situations, $K_s << S^0$, so:

$$\frac{1}{SRT_{min}} \approx Yk - b = \mu_m - b$$

  - Process safety factor, SF

$$SF = \frac{SRT_{des}}{SRT_{min}}$$

SRT_{des} = design SRT (d)

Design & operating parameters

- **F/M ratio (food to microorganism ratio)**

$$F/M = \frac{QS^0}{VX} = \frac{S^0}{\tau X}$$

F/M = food to microorganism ratio (g bsCOD/g VSS-d)

  – High F/M $\Rightarrow$ low steady-state SRT

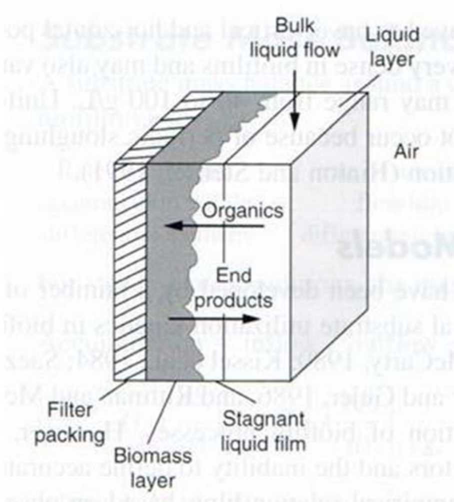
- **Volumetric organic loading rate**
  – The amount of BOD or COD applied to the aeration tank volume per day

$$L_{org} = \frac{QS^0}{V \cdot (10^3\ g/kg)}$$

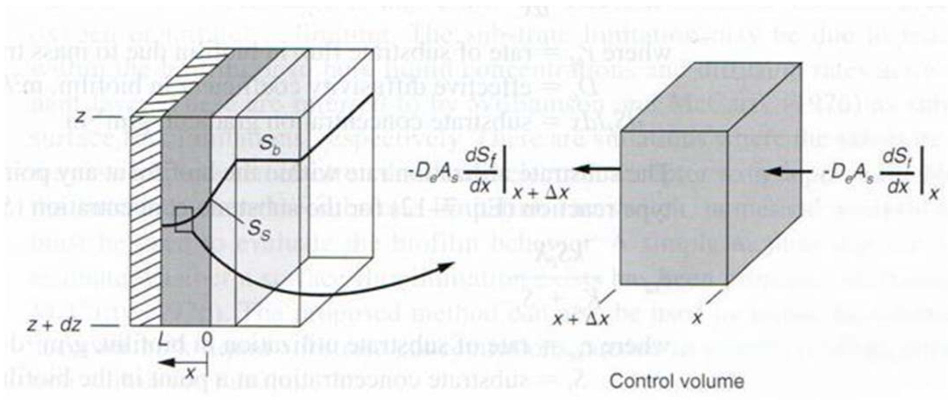
L_{org} = volumetric organic loading rate (kg bsCOD/m^3-d)

Modeling attached growth processes

- **An additional process: diffusion**
  - Diffusion of:
    - Substrates, O_2, nutrients (from bulk liquid to biofilm)
    - Biodegradation products (from biofilm to bulk liquid)
  - For modeling, assume stagnant liquid film on the biofilm surface (recall film theory!)
  - Analysis quite complicated, still not fully developed



<Schematic view of the cross section of a biofilm>



<Analysis of substrate concentration in idealized biofilm>

Aerobic oxidation – operation issues

- Major issue: **settling at the secondary clarifier**
  - **Sludge bulking**
    - Bulking sludge: sludge with poor settling characteristics
    - Bulking sludge development depends on aeration tank configuration, environmental factors, operating conditions, etc.
    - Sludge volume index (SVI): the volume occupied per g of settled sludge after 30 min of settling (SVI > 150 mL/g is considered as bulking sludge)
  - **Foaming**
    - Related to the development of bacteria with hydrophobic cell surfaces that attach to air bubbles

Foam caused by Gordonia amarae accumulated on the surface of an aeration tank

Aerobic oxidation – operation issues

- **Environmental factors**
  - pH should be near neutral (pH ~ 6.0-9.0 OK)
  - DO concentration of ~2.0 mg/L (generally OK if DO > 0.5 mg/L)
  - Availability of nutrients for industrial wastewater
  - Presence of toxic substances
    - Generally, heterotrophic, aerobic bacteria are better at tolerating toxic substances than microorganisms used for nitrification or methanogenesis