Fundamentals of biological treatment II

Modeling bacterial growth

- As bacteria consume the substrate, some (specific) portion is used for energy and the other is used to produce new biomass

  → new growth of cells is directly proportional to the substrate utilized

- So, the bacteria growth rate from substrate utilization is expressed as:

$$r_g = \left(\frac{dX_a}{dt}\right)_{growth} = \frac{\mu_m X_a S}{K_s + S}$$

r_g = bacteria growth rate from substrate utilization (g/m^3-d)

μ_m = maximum specific bacteria growth rate (1/d)

with $r_g = Y r_{su}$ and $\mu_m = kY$

Y = true yield (g biomass/g substrate utilized)

→ This is the biomass yield we studied!

Modeling bacterial growth

- The substrate utilization rate can be written as:

$$r_{su} = \frac{\mu_m X_a S}{Y(K_s + S)}$$

- Another form of Monod equation:

$$\mu = \frac{1}{X_a} \cdot \left(\frac{dX_a}{dt}\right)_{growth} = \frac{\mu_m S}{K_s + S}$$

μ = <u>specific</u> bacteria growth rate (1/d)

Biomass decay

- Microorganism concentration **<u>decrease</u>** when the substrate is depleted
- This is true in the presence of substrates as well!
- Decay (or endogenous decay endogenous respiration)
  - Cell maintenance energy needs
  - Cell lysis due to death or stress from environmental factors
  - Predation (protozoa, etc.)
  - Generally assumed to be proportional to cell concentration:

$$\left(\frac{dX_a}{dt}\right)_{decay} = -bX_a$$

X_a = active biomass concentration [M/L^3]
b = decay coefficient [T^{-1}]

  - b in the range of 0.05 ~ 0.20 d^{-1}

Modeling bacterial growth

- **Net biomass growth rate**

  (net biomass growth)

  = (biomass growth according to substrate utilization) – (biomass decay)

$$r_X = Y r_{su} - bX_a = Y\frac{kX_aS}{K_s + S} - bX_a$$

r_X = net biomass growth rate (g VSS/m^3-d)

- **Net specific biomass growth rate**

$$\mu_{net} = \frac{r_X}{X_a} = Y\frac{kS}{K_s + S} - b$$

μ_{net} = net specific biomass growth rate (1/d)

Microbial growth kinetics

- Actually, the Monod kinetics can be applied for any growth-limiting substrates
  - Substrates can be e^- donor, e^- acceptor, nutrients, etc.
  - Quite often the e^- donor is limiting while others are available in excess – for growth kinetics, the term substrate generally refers to e^- donor

- **Generalized equation**
  - If factors other than e^- donor can be limiting, include those as well!

Microbial growth kinetics

ex) for aerobic, heterotrophic bacteria; if bsCOD, DO, and ammonia-N are limiting:

$$r_{su} = \left[\frac{\mu_{H,max} S_s}{Y_H (K_s + S_s)}\right] \left(\frac{S_o}{K_o + S_o}\right) \left(\frac{S_{NH}}{K_{NH} + S_{NH}}\right) X_{a,H}$$

$\mu_{H,max}$= maximum specific growth rate of heterotrophic bacteria (1/d)

Y_H = heterotrophic bacteria synthesis yield coefficient (g VSS/g COD used)

$X_{a,H}$ = active heterotrophic bacteria concentration (g VSS/m^3)

S_i = concentration for variable i (i = substrate, DO, ammonia-nitrogen) (g/m^3)

K_i = half-velocity constant for variable i (g/m^3)

here, the term "substrate" is used for bsCOD (the e^- donor)

Microbial growth kinetics

Typical range/values of kinetic coefficients for activated sludge process

Coefficient	Unit	Value[a]	
		Range	Typical
k	g bsCOD/g VSS-d	4-12	6
K_s	mg/L BOD	20-60	30
	mg/L bsCOD	5-30	15
Y	mg VSS/mg BOD	0.4-0.8	0.6
	mg VSS/mg COD	0.4-0.6	0.45
b	1/d	0.06-0.15	0.10

[a]At 20^oC, from Metcalf & Eddy / Aecom

Oxygen uptake rate & temperature effect

- **Rate of oxygen uptake**
  - Recall that the COD of biomass was:

    1.42 g COD/g VSS for $\mathbf{C_5H_7O_2N}$

$$r_o = r_{su} - 1.42 r_X$$

r_o = oxygen uptake rate (g O_2/m^3-d)
r_{su} = substrate utilization rate (g bsCOD/m^3-d)
r_X = net biomass growth rate (g VSS/m^3-d)

- **Effect of temperature**
  - Recall the modified van't Hoff-Arrhenius relationship:

$$k_T = k_{20}\theta^{(T-20)}$$

θ = temperature correction factor,
range from 1.02 to 1.25

Total VSS and active biomass

- Note that total VSS includes not only active biomass but also:
  - Cell debris resulting from endogenous decay
  - Non-biodegradable VSS (nbVSS) in the influent wastewater
- During cell death, some portion dissolves into the liquid for consumption by other bacteria, and the other portion remains as non-biodegradable material
  - 10~15% of original cell weight is converted to nbVSS
  - This is referred to as cell debris

- **Rate of production of cell debris**

$$r_{X,i} = f_d b X$$

$r_{X,i}$= rate of cell debris production (g VSS/m^3-d)

f_d = fraction of biomass that remains as cell debris,
0.10-0.15 g VSS/g biomass VSS depleted by decay

Total VSS and active biomass

- The **total VSS production rate** in the aeration tank of an activated sludge process

$$r_{X,VSS} = Yr_{su} - bX_a + f_d bX_a + QX_i^{o}/V$$

net biomass VSS from bsCOD — *nbVSS from cells* — *nbVSS in influent*

$r_{X,VSS}$ = total VSS production rate (g/m^3-d)
Q = influent flowrate (m^3/d)
X_i^{o} = influent nbVSS concentration (g/m^3)
V = volume of aeration tank (m^3)

- **The active fraction of biomass**

$$F_{X,act} = (Yr_{su} - bX_a)/r_{X,VSS}$$

$F_{X,act}$ = active fraction of biomass in MLVSS, g VSS/g VSS

Total VSS and active biomass

- **Net biomass yield**
  - The ratio of the net biomass growth rate and the substrate utilization rate

$$Y_{bio} = r_X / r_{su}$$

Y_{bio} = net biomass yield, g biomass/g substrate used

- **Observed yield**
  - The ratio of the actual solids production rate and the substrate utilization rate for a system

$$Y_{obs} = r_{X,VSS} / r_{su}$$

Y_{obs} = observed yield, g VSS produced/g substrate removed

Total VSS and active biomass

Q: An aerobic complete-mix treatment process is used to treat wastewater. The amount of bsCOD in the influent wastewater is 300 g/m^3 and the influent nbVSS concentration is 50 g/m^3. The influent flowrate is 1000 m^3/d, the aerobic tank biomass concentration is 2000 g/m^3, the reactor bsCOD concentration is 2.4 g/m^3, and the reactor volume is 335 m^3. If the cell debris fraction (f_d) is 0.10, determine: **i) the net biomass yield**, **ii) the observed VSS yield**, and iii) **the active biomass fraction in the MLVSS**. Use the following kinetic parameters.

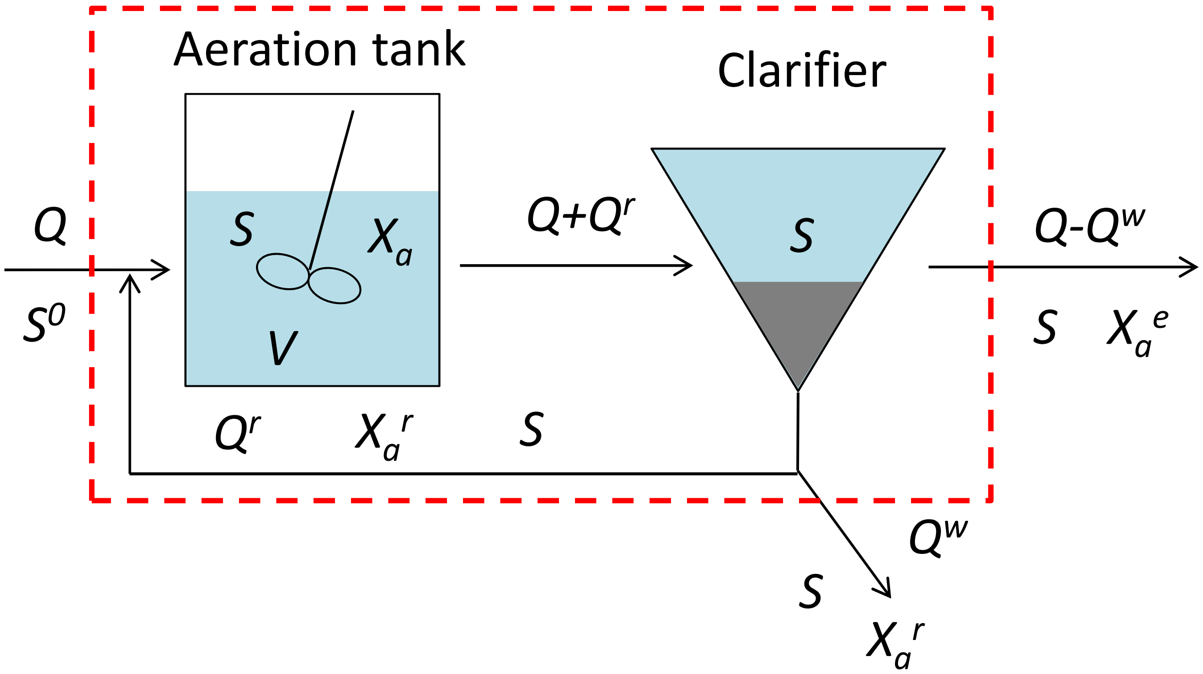
k = 6 g bsCOD/g VSS-d

K_s = 15 g bsCOD/L

Y = 0.45 mg VSS/mg bsCOD

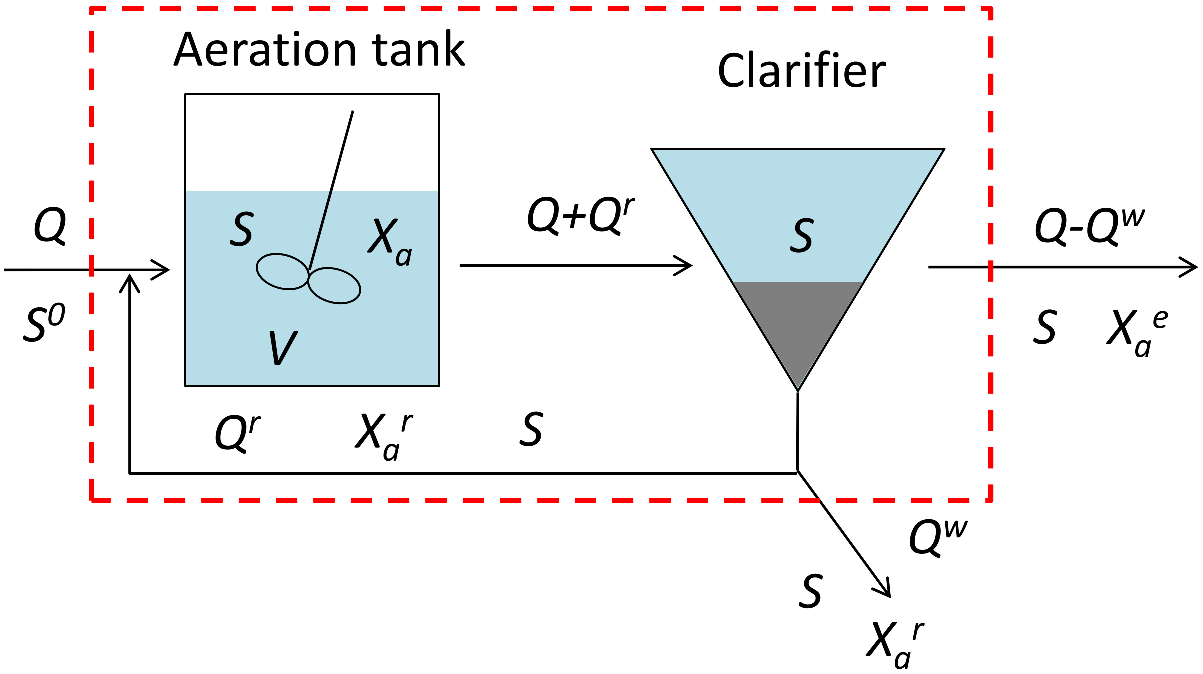
b = 0.10 g VSS/g VSS-d

Suspended growth processes



– The majority of the settled sludge in the secondary clarifier is returned to the aeration tank to obtain high biomass concentration
– Some portion of the settled sludge (due to net growth of biomass) is removed from the system for steady state operation

Suspended growth processes



- General assumptions:
  - Biodegradation of substrate occurs in the aeration tank only, not in the clarifier
  - No active biomass in the influent

Key variable - SRT

- **S**olids **R**etention **T**ime (or mean cell residence time)
- The average time the activated sludge solids are in the system
- So SRT can be defined as:

  (Amount of solids in the system) / (rate of solids exiting the system)

Assuming that the amount of solids in the clarifier is negligible compared to that in the aeration tank,

$$SRT = \frac{VX_a}{(Q - Q^w)X_a{}^e + Q^w X_a{}^r}$$

SRT = solids retention time (d)
V = aeration tank volume (m^3)
Q = influent flowrate (m^3/d)
X_a = active biomass concentration in the aeration tank (g VSS/m^3)
Q^w = waste sludge flowrate (m^3/d)
$X_a{}^e$ = active biomass concentration in the effluent (g VSS/m^3)
$X_a{}^r$ = active biomass concentration in the return activated sludge line (g VSS/m^3)