KEY TAKE-HOME MESSAGES ON WASTEWATER MICROBIOLOGY

"MICROBES": Collective term we'll use

BACTERIA MOLDS
FUNGI PROTOZOA
("BUGS")

HETEROTROPHS: GREEK: "OTHER FEED"

Eat organic matter as both energy source & carbon source

① $\text{"}CH_2O\text{"} + O_2 \rightarrow CO_2 + H_2O + \text{ENERGY}$

② $n\,\text{"}CH_2O\text{"} \rightarrow [CH_2O]_n$ (STRUCTURE)

AUTOTROPHS: GREEK: "SELF FEED"

Use CO_2 as carbon source (hence they "make their own food")

GREEN PLANTS: Photoautotrophs BACTERIA: Chemoautotrophs

"Burn" (oxidize) inorganic molecules for energy

① $H_2O + CO_2 + \text{energy} \rightarrow \text{"}CH_2O\text{"}$

② E.g.: $NH_4^+ + 2O_2 \rightarrow NO_2^- + 2H_2O + \text{energy}$

METABOLISM: Heterotrophs oxidize ("burn") organic matter. Oxidation means removing electrons, so eventually have to "dump" the e^- somewhere

"TERMINAL ELECTRON ACCEPTOR"

BEST: O_2 $2e^- + 2H^+ + O_2 \rightarrow H_2O$

AEROBIC METABOLISM (Respiration)

- YIELDS A LOT OF ENERGY
- RESULTS IN FAST GROWTH, FAST BREAKDOWN OF "FOOD"
- LOTS OF CELL MASS PRODUCED

HENCE, best choice for fast removal of BOD

But leaves a lot of cell mass behind (sludge)

ANAEROBIC METABOLISM

IF NO O_2 IS AVAILABLE some "anaerobes" use "alternative electon acceptors"

FERMENTATION:

E.g. $\text{"}CH_2O\text{"} + H_2O \rightarrow C_3H_7COOH + CO_2 + H_2 + \text{energy}$

BUTYRIC ACID

... $\rightarrow$ ACETIC ACID + CH_4 + CO_2

METHANE

SUMMARY:

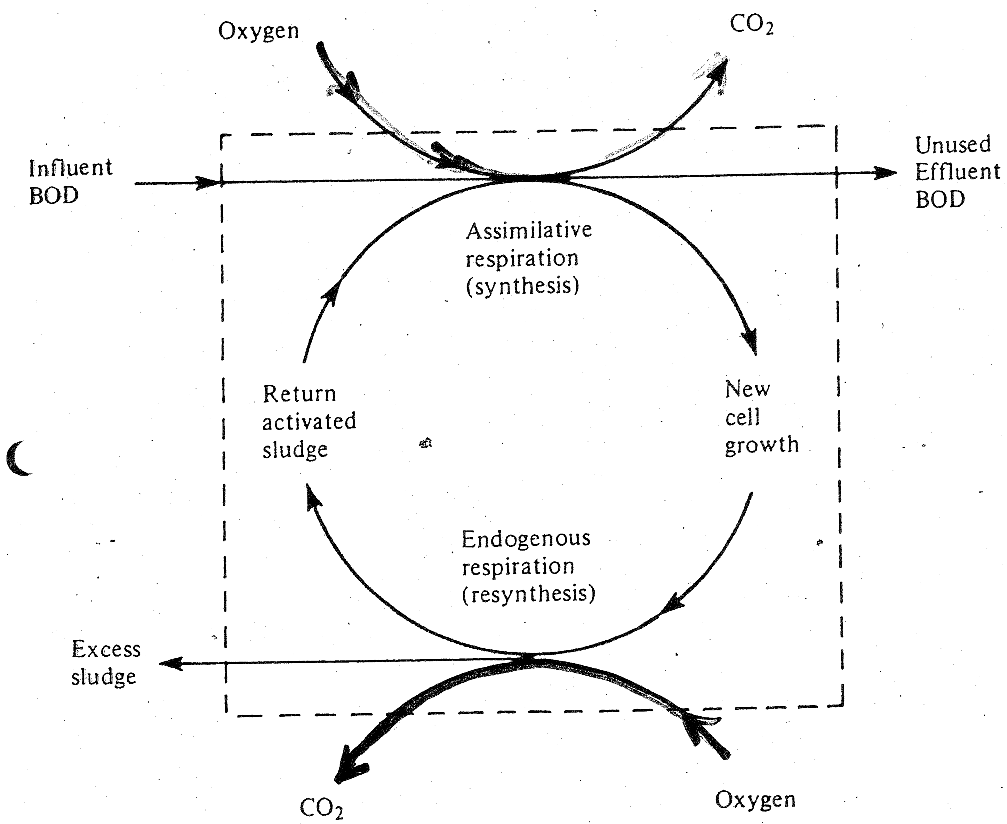
AEROBIC vs. ANAEROBIC

AEROBIC:

- Fast breakdown of soluble wastes (BOD)
- Low odor production
- No gas production (besides CO_2)
- pH control not difficult
- Produces lot of cells, (solids) (Liquid BOD → solid cells)
- Must supply plentiful O_2 / Not good for very concentrated waste

ANAEROBIC:

- Slower growth
- Produces lots of odor + CH_4 GAS
- Organic Acids: Harder to control pH
- Works fine with highly concentrated wastes
- Reduces biomass (dead cells → org. acids → CH_4, CO_2)
- No O_2 supply problems
- CH_4 gas can be valuable product



igure 12.31 Generalized biological process reactions in the activated-udge process.

MICROBIAL GROWTH DYNAMICS

SIMPLEST CASE:

- UNLIMITED SUBSTRATE (FOOD)
- NO LIMITING MICRONUTRIENTS (e.g. N, P, K, trace elements)

⇨ **FIRST-ORDER (EXPONENTIAL) GROWTH**

$X \equiv$ cell population density { cells/mL, mg/L }

$$\frac{dX}{dt} = \mu X$$

$\mu \equiv$ SPECIFIC GROWTH RATE

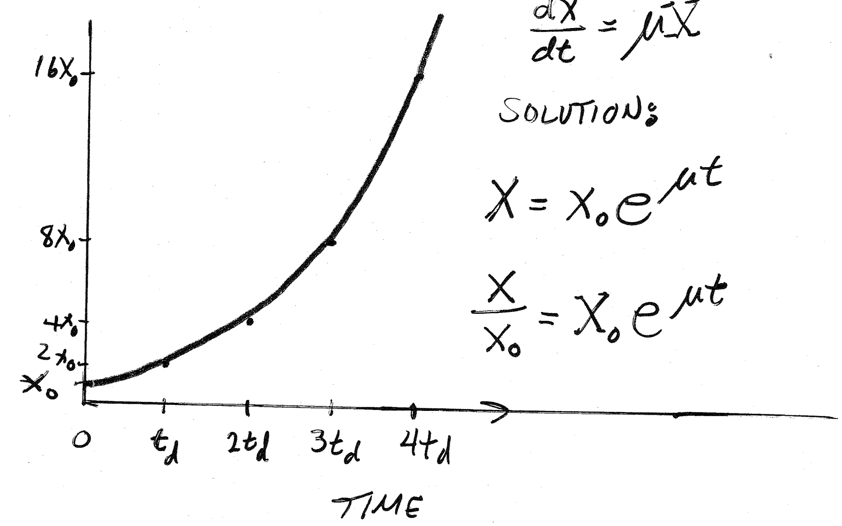
$$\mu = \frac{\text{RATE OF CHANGE OF POP.}}{\text{CELL DENSITY}}$$

UNITS: $\frac{\text{cells/hr}}{\text{cells}} = \underline{hr^{-1}}\ (T^{-1})$

IN SIMPLEST CASE:

μ = constant = "% change per time"

EXPONENTIAL GROWTH



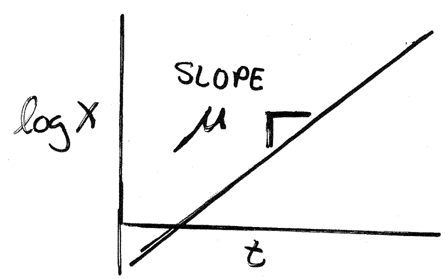
$$\frac{dX}{dt} = \mu X$$

SOLUTION:

$$X = X_0 e^{\mu t}$$

$$\frac{X}{X_0} = X_0 e^{\mu t}$$

DOUBLING TIME OF POPULATION: $\frac{X}{X_0} = 2 = e^{\mu t_d}$



$$\ln 2 = \mu t_d$$

$$\boxed{t_d = \frac{\ln 2}{\mu} = \frac{0.69}{\mu}}$$

DEATH: Assume linear proportion of population

NET GROWTH: $\frac{dX}{dt} = \mu X - kX$

ENZYME KINETICS (Michaelis-Menten)

$$\underset{\text{ENZYME}}{E} + \underset{\text{SUBSTRATE}}{S} \underset{k_2}{\overset{k_1}{\rightleftharpoons}} \underset{\text{COMPLEX}}{[ES]} \xrightarrow[\text{SLOW}]{k_3} \underset{\text{(RECYCLED) ENZYME}}{E} + \underset{\text{PRODUCT}}{P}$$

FAST

(DEF'N OF CATALYSIS: E "comes back")

Key to problem: Focus on [ES]

$$\frac{d[ES]}{dt} = \underset{\substack{(+)\\ \text{FORMATION}}}{k_1[E][S]} - \underset{\substack{(-)\\ \text{"BACK" LOSS}}}{k_2[ES]} - \underset{\substack{(-)\\ \text{"FORWARD" LOSS}}}{k_3[ES]}$$

And

$$\frac{d[P]}{dt} = +k_3[ES]$$

If formation of ES is "fast" then assume equl'n [ES]: $\frac{d[ES]}{dt} \cong 0$

If $\frac{d[ES]}{dt} = 0$ then

$$k_1[E][S] = \underbrace{k_2[ES] + k_3[ES]}$$

$$k_1[ES][S] = (k_2 + \cancel{k_3})[ES]$$

SMALL COMPARED TO k_2

$$\frac{k_2}{k1} = \frac{[E][S]}{[ES]} \equiv K_M$$

⇐ AN EQUILIBRIUM CONSTANT FOR THE FORMATI[ON] OF THE ES COMP[LEX]

Use MASS BALANCE: $E_T = [E] + [ES]$

substitute for [E]:

$$[ES] = \frac{E_T[S]}{K_M + [S]}$$ and since $\frac{d[P]}{dt} = k_3[ES]$

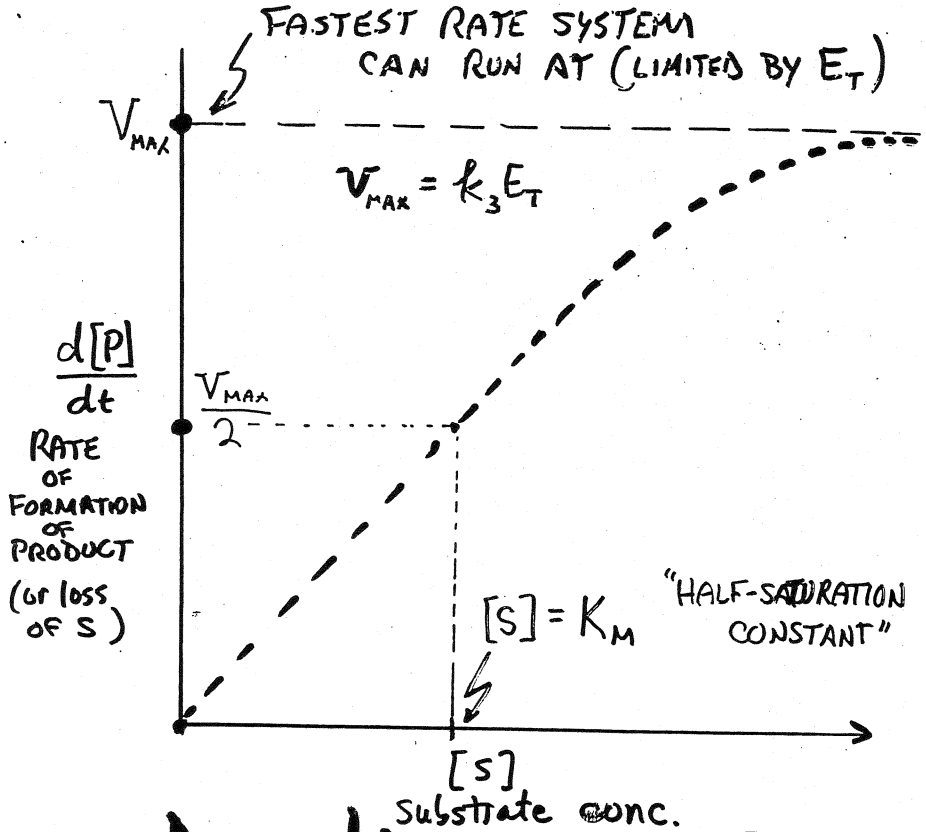
$$\frac{d[P]}{dt} = \frac{(k_3 E_T)[S]}{K_M + [S]}$$

OR

$$\frac{d[P]}{dt} = \frac{V_{max}[S]}{K_M + [S]}$$

$$V \cdot \frac{C}{C + K_s}$$

MICHAELIS-MENTEN RATE EXPRESSION

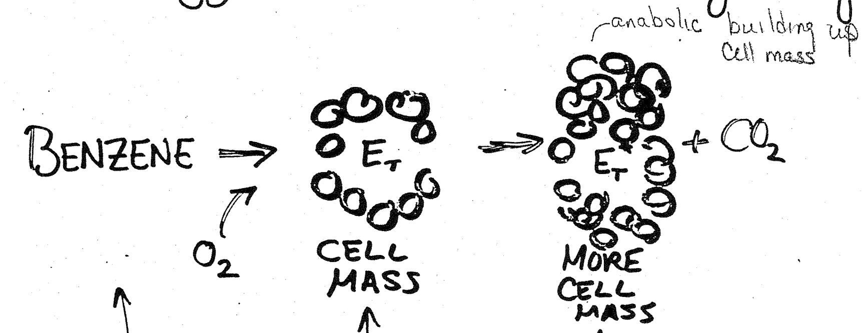


$[S] \ll K_M$	$[S] \approx K_M$	$[S] \gg K_M$
$\frac{d[P]}{dt} \approx \frac{V_{MAX}}{K_M}[S]$	$\frac{d[P]}{dt} = \frac{V_{MAX}[S]}{K_M + [S]}$	$\frac{d[P]}{dt} \approx V$
RATE IS LINEAR WITH [S]	RATE IS HYPERBOLIC WITH [S]	RATE IS CONSTANT (INDEP. OF [S])

So far we assumed a FIXED AMOUNT OF ENZYME

But what if the bugs that catalyze the reaction are growing?

E.g.



$$[S] + [E] \rightleftharpoons [ES] \rightarrow [P]$$

$$[S] + q[P] \rightleftharpoons [ES] \rightarrow [P]$$ USE "CELL QUOTA"

Cell quota

$$q[P] = E_T \leftrightarrow E_T \propto [P]$$

TOT. ENZYME $\propto$ CELL MASS

So take prior eqn:

$$\frac{d[P]}{dt} = \frac{k_3 E_T [S]}{K_M + [S]} = \frac{k_3 q [P][S]}{K_M + [S]}$$

DEFINE: $k_3 q \equiv \mu_M$

$$\boxed{\frac{d[\text{CELLS}]}{dt} = \frac{\mu_M [\text{CELLS}][S]}{K_M + [S]}}$$

maximum growth rate

$K_M + [S]$

This explains the growth of the bacteria (Monod Growth Kinetics)

("Moh-Noh")

Convenient to normalize the rate to the # of cells present:

$$\frac{d[\text{cells}]}{dt} \Big/ [\text{cells}] \equiv \mu = \frac{\mu_m [S]}{K_M + [S]}$$

SPECIFIC GROWTH RATE

UNITS: 1/time

"Percent change in population per unit time"

E.g. $\mu = 3\ hr^{-1}$

LOOKS LIKE MICHAELIS-MENTEN ENZYME RATE LAW (NO SURPRISE)

At very high [S]

$\mu \approx \mu_{max}$

$$\frac{dP}{dt} = \mu_m[P] \Rightarrow P = P_0 e^{\mu_m t}$$

EXPONENTIAL GROWTH

Means "Grows @ 3 cells/hr for every cell present"

In exponential growth stage we can say

$$\frac{P}{P_0} = 2.0 = e^{\mu_m \tau_d}$$

Population DOUBLES

$$\tau_D = \frac{\ln 2}{\mu_{max}} = \frac{0.693}{\mu_{max}}$$

"DOUBLING TIME"

rate of S-removal

$$r_x = -Y r_s - k_e X_v$$

Yield

$$\frac{\text{mass of organisms}}{\text{mass of substrate removed}}$$

Decay

VSS ("cell mass")

CAN SIMPLIFY BUT BEST TO ACCOUNT FOR GROWTH AND DECAY

TYPICAL: $Y = 0.6\ \frac{g\text{-}VSS}{g\text{-}BOD_5}$

$k_e = 0.06\ d^{-1}$

"6% DEATH PER DAY"

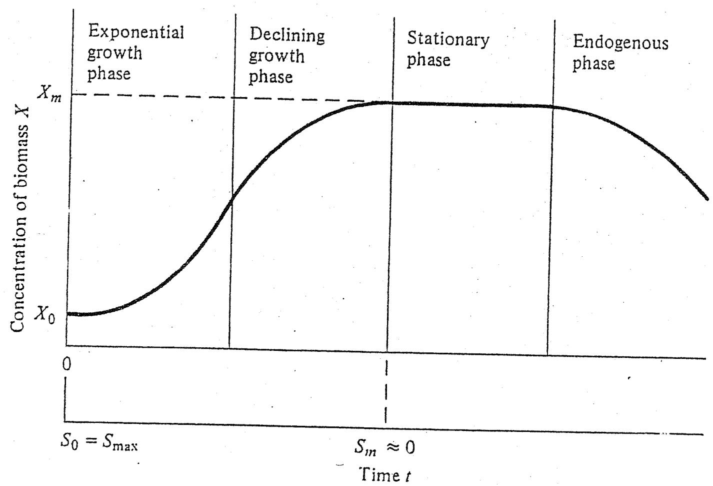


Figure 12.5 Characteristic growth phases of a pure culture of bacteria.

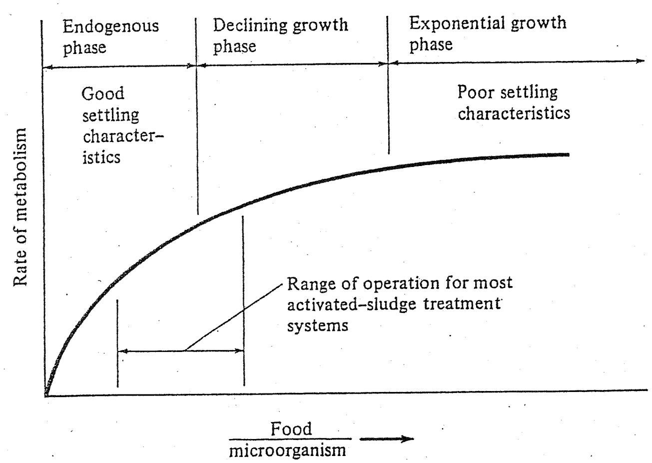


Figure 12.9 Rate of metabolism versus increasing food/microorganism ratio.

LOAD CALCULATIONS

$S_{IN} = 200$ mg/L BOD

$(200 \frac{mg}{L})(8.34) = 1,670$ lbs/MG

$Q_{TOT} = 5$ MGD (Approx. 40,000 people)

LOAD = 8,340 lbs/d

$$\frac{8,340}{\text{lb/d/1000ft}^3} = 167,000 \text{ ft}^3 \qquad D = 15 \text{ ft}$$

$$A = \frac{167,000 \text{ ft}^3}{15 \text{ ft}} = 11,100 \text{ ft}^2$$

$$\text{radius} = \left(\frac{11,100 \text{ ft}^2}{\pi}\right)^{\frac{1}{2}} = 60 \text{ ft}$$

HYDRAULIC LOADING?

$$\frac{(5 \times 10^6 \text{ gpd})/(1440 \frac{\text{min}}{d})}{11,100 \text{ ft}^2} = 0.31 \frac{\text{gpm}}{\text{ft}^2}$$

This is less than recommended 1.0 so RECIRCULATE 2:1 (Recirc Ratio = 2 or so)

Recirc Rate = 0.5 $\quad$ D = 18 m

S_i = 130 mg/L $\quad$ d = 2.1 m

Q = 280 gpm $\quad$ T = 18°c

Q = 1530 m³/d

Recirculation Flow = 0.5 × 1530 = 765 m³/d

BOD Load = $1530 \frac{m^3}{d} \times 130 \frac{mg}{L} \times \frac{kg/m^3}{1000\ mg/L} = 200 \frac{kg}{d}$

Area = $\pi\left(\frac{D}{2}\right)^2 = 254\ m^2$

Vol = 254 m² × 2.1 m 533 m³

BOD LOAD CHECK:

$$\frac{200\ kg/d}{533\ m^3} = 375 \frac{g}{m^3 d} = 23.5 \frac{lb}{d \cdot 1000 ft^3}$$

< 50 (20-60 range) so OK

HYDRAULIC LOAD CHECK:

$$\frac{(1530 + 765)\frac{m^3}{d}}{254\ m^2} = 9.04 \frac{m^3}{m^2 d} \times \frac{35\ ft^3}{m^3} \cdot \frac{d}{1440\ min} \cdot \frac{0.093\ m^2}{ft^2} \cdot \frac{7.48\ gal}{ft^3}$$

= 0.15 gpm/ft ← (SEEMS SKIMPY TO ME)

EFFICIENCY:

Recirc. Factor: $F = \frac{1+R}{(1+0.1R)^2} = \frac{1+0.5}{(1+0.05)^2} = 1.36$

EFF. $E_{20} = 100 / 1 + 0.0561\left(\frac{W}{VF}\right)^{0.5} = \frac{100}{1 + 0.056\left(\frac{23.5}{1.36}\right)} = 81.1\%$ $\quad$ 75.7%

EFFLUENT BOD: 130 - 76% = 32 mg/L